The Russian Aphasia Test: The first comprehensive, quantitative, standardized, and computerized aphasia language battery in Russian

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Abstract

The lack of standardized language assessment tools in Russian impedes clinical work, evidence-based practice, and research in Russian-speaking clinical populations. To address this gap in assessment of neurogenic language disorders, we developed and standardized a new comprehensive assessment instrument – the Russian Aphasia Test (RAT). The principal novelty of the RAT is that each subtest corresponds to a specific level of linguistic processing (phonological, lexical-semantic, syntactic, and discourse) in different domains: auditory comprehension, repetition, and oral production. In designing the test, we took into consideration various (psycho)linguistic factors known to influence language performance, as well as specific properties of Russian. The current paper describes the development of the RAT and reports its psychometric properties.

A tablet-based version of the RAT was administered to 85 patients with different types and severity of aphasia and to 106 age-matched neurologically healthy controls. We established cutoff values for each subtest indicating deficit in a given task and cutoff values for aphasia based on the Receiver Operating Characteristic curve analysis of the composite score. The RAT showed very high sensitivity (> .93) and specificity (> .96) substantiating its validity for determining presence of aphasia. The test's high construct validity was evidenced by strong correlations between subtests measuring similar linguistic processes. The concurrent validity of the test was also strong as demonstrated by a high correlation with an existing aphasia battery. Overall high inter-rater and test-retest reliability were obtained.

The RAT is the first comprehensive aphasia language battery in Russian with properly established psychometric properties. It is sensitive to a wide range of language deficits in aphasia and can reliably characterize individual profiles of language impairments. Notably, the RAT is the first comprehensive aphasia test in any language to be fully automatized for administration on a tablet, maximizing further standardization of presentation and scoring procedures.

Keywords

Aphasia, language, assessment, standardized testing, psychometrics, Russian

Introduction

The Russian language is spoken by about 260 million people worldwide, making it the 8th commonly spoken language in the world [1]. Still, there is a dramatic dearth of standardized tests for assessment of language disorders in Russian speakers [2]. Historically, a qualitative approach to clinical assessment grounded in Luria's neuropsychological theory has dominated the clinical field in Russia [3,4]. Patients are assessed with custom neuropsychological probes, targeting various cognitive and language domains; based on the pattern of performance, a conclusion regarding their language status is made by a clinician, which cannot be entirely objective by definition. While this approach is highly valuable for understanding the mechanisms of cognitive impairments and their neural substrate on an individual basis, it is not readily quantifiable or easily generalizable, and is highly dependent on the expertise of the clinician doing the assessment. This, overall, impedes evidence-based practice. Currently, the landscape for language assessment in Russian looks barren, and there is significant clinical and research need for standardized tools.

Up to now, the Assessment of Speech in Aphasia (ASA, in Russian *Metodika otsenki rechi pri afazii*; [5]) has been the most commonly used quantitative battery in Russian for assessment of language deficits in aphasia, although it remains largely unfamiliar to the global research community. The ASA includes ratings of conversational speech and a set of production and comprehension subtests at the word and sentence levels (see [6] for a detailed description of the subtests in English). State-of-the-art at the time of its creation, it incorporated comprehension and production of both nouns and verbs and tested syntactic constructions of various complexity. Also, the test was standardized on an impressively large sample (*N* = 234) of people with aphasia

(PWA). However, it falls short of contemporary psychometric standards in several important aspects. First of all, the test lacks normative data on performance by individuals without aphasia. In the original publication [5], it is simply acknowledged that 30 healthy controls were tested to ensure that all items could be completed by individuals without brain injuries, but no actual normative data were provided. Subsequently, it was implicitly assumed that individuals without a language disorder should perform perfectly on the test, which is not a realistic premise. In practice, such expectation makes the clinicians determine the aphasia cutoff score subjectively on an individual basis. Secondly, the analyses lack statistical rigor, with the main focus being on exploring patterns of raw subtest scores in different aphasia subtypes. No transformations of raw scores are provided, making comparison between subjects and subtests challenging. Thirdly, formal reliability metrics of the test were not established, which is especially problematic for the subjective rating scale of the discourse subtests. Further, the ASA lacks subtests targeting several important language levels and domains (e.g., repetition and phonological processing are not assessed, comprehension is not tested at the discourse level). Finally, it has outdated visual stimuli (that some of the younger patients today have a hard time recognizing), and the word frequency counts that guided verbal stimuli selection are obsolete.

Another clinically adopted Russian battery is that of Vasserman and colleagues [7]. The speech and language subtests are a part of a comprehensive neuropsychological examination and were devised to provide a diagnosis of language deficits according to Luria's aphasia classification [3,4]. Unlike the ASA, Vasserman and colleagues [7] presented normative data of neurologically healthy individuals (*N* = 147) in three age groups; however, data on performance of PWA were not reported. Theoretically grounded in Luria's approach to neuropsychological diagnostics, it is a useful guide for practicing clinicians who work within this framework. However, the method of Vasserman and colleagues [7] has several important shortcomings that limit its clinical applications and prevent its use for research purposes. Aspects of speech and language, such as spontaneous speech, naming, repetition, fluency etc., are assessed based on a custom four-point scale that blends qualitative and quantitative metrics. The items in the tasks are few in number, and psycholinguistic variables of the materials are not controlled. With respect to psychometric properties, only test-retest reliability in healthy controls is explicitly reported. To sum up, while the ASA [5] and the method of Vasserman and colleagues [7] continue to be used widely for quantification of language deficits in Russian-speaking PWA, they do not conform to contemporary standards for comprehensive standardized assessment of language.

To explore a possible alternative, Ivanova and Hallowell [8] validated a short version of the previously translated into Russian Bilingual Aphasia Test in PWA [9], but concluded that the translated version of the test battery has problematic psychometric properties. Since the test was never normed on a sample of healthy age-matched controls, criterion validity along with specificity and sensitivity could not be established. Additionally, some of the items were originally incorrectly translated into Russian, and some of the visual stimuli were unrecognizable. This work alerts of the pitfalls of using tests directly translated from one language into another bypassing the necessary stages of test development, adaptation, norming and standardization.

In addition to the aforementioned comprehensive test batteries, several other tests have been adapted to Russian recently that serve screening purposes [10,11] or target a specific language component [8,12]. For assessment of language deficit in the acute post-stroke period, the Aphasia Rapid Test [13] has been adapted to Russian and standardized on a cohort of PWA and healthy individuals [10]. This test can be administered in 3-5 minutes and demonstrates high sensitivity in identifying speech/language disorders, although without further differentiation between aphasia and motor speech deficits. For the latter purpose, the Aphasia Bedside Check (ABC) [14] was adapted to Russian. This screening tool evaluates language comprehension and production along with verbal fluency, repetition, articulation, and reading aloud. To investigate whether PWA in acute stage have phonological, semantic or syntactic deficits, the Russian translation of the ScreeLing test [15] is used. The norms for the tablet administration of the Russian version of the shortened Token Test [16] are also currently being analyzed [11]. In the test, tokens of various shape and color are presented to participants, who have to perform different actions with them (touch, rearrange, etc.) following oral instructions. In this manner, the test establishes presence of aphasia and its severity through assessment of auditory comprehension. The standardization of the Russian versions of the ABC, the ScreeLing and the shortened Token Test are currently underway; however, their use will be limited to screening purposes.

With regards to tests targeting specific language domains, Hallowell and Ivanova [17] normed the Russian multiple-choice version of the Revised Token Test [18] in both healthy controls and PWA. The test specifically assesses syntactic aspects of auditory comprehension. It requires matching of sentences of increasing complexity that describe the spatial location of tokens to pictures. Finally, the Verb and Sentence Test (VAST) [19–21] has been adapted to Russian [12]. It has several subtests that assess production and comprehension of isolated verbs and sentences. The VAST provides a profile of language impairment with the focus on verbs and grammar; however, no norms are currently available for the Russian version.

All of these tests are either brief and coarse screening batteries meant for quick bedside assessment or target a specific linguistic domain. Thus, they cannot substitute a detailed language evaluation or provide a comprehensive picture of the patient’s linguistic strengths and weaknesses across language domains on the same scale. The few currently existing quantitative comprehensive language tests in Russian [5,7,9] have not been normed properly, lack tests targeting several important domains and linguistic levels, and have outdated stimuli. This lack of proper diagnostic tools makes it challenging to reliably evaluate and quantify the severity of linguistic deficits in individuals with various aphasia types, which, in turn, precludes systematic approaches to treatment in clinical practice and conduction of quantitative research. A comprehensive aphasia battery developed specifically for the Russian language is much needed. To address this gap, we developed and standardized a new comprehensive aphasia test – the Russian Aphasia Test (RAT).

In development of the RAT, we aimed to integrate the most current neurolinguistic and psychometric practices. The principal novelty of the RAT is that each subtest corresponds to a specific level of linguistic processing (phonological, lexical-semantic, syntactic, discourse) within the following domains: auditory comprehension, repetition, and oral production. Similar to a recently developed Quick Aphasia Battery (QAB) [22], we designed the RAT such that instead of specifying aphasia types, a multidimensional characterization of impaired and spared aspects of language functioning could be made. The selection of specific tasks for each processing level was motivated by the structure and materials of contemporary well-established standardized aphasia tests in other languages (Boston Diagnostic Aphasia Examination [23], Comprehensive Aphasia Test [24], Northwestern Assessment of Verbs and Sentences [25], Northwestern Naming Battery

[26], Psycholinguistic Assessments of Language Processing in Aphasia [27], Verb and Sentence Test [19,20], Western Aphasia Battery-Revised [28]; see also [29]). Additionally, we took into consideration various (psycho)linguistic factors known to influence performance, as well as the specific structural and phonetic properties of the Russian language. We aimed to develop a test that would reliably identify impaired language processing and also provide a detailed evaluation of linguistic strengths and weaknesses in a clinically feasible time. We selected items ranging in difficulty, so that we could capture the full spectrum of aphasic language disorders and would be able to specify profile of impairment in individuals with different aphasia syndromes. Additionally, the RAT, to the best of our knowledge, is the first comprehensive aphasia test that is fully automatized for presentation and response recording on a tablet, further optimizing and standardizing administration and scoring procedures and simplifying data collection.

The goals of the current paper are to provide a detailed background on the construction of the RAT, describe its components, explain scoring procedures, and establish its psychometric properties. With respect to the last goal, we aimed to evaluate diagnostic properties of the RAT in terms of differentiating between PWA and healthy controls, its construct and concurrent validity, and inter-rater and test-retest reliability.

Materials and methods

Participants

Neurologically healthy individuals (NHI) group

One hundred and six native speakers of Russian without history of neurological or psychiatric disorders or substance abuse participated in the study (see Table 1 for participants' demographic characteristics). The level of formal education varied from secondary school (typically 10 years in Russia) to a university degree (typically 15 years), with the majority of the participants (80.2%) having some form of higher education degree (12-15 years). Most participants were right-handers (*N* = 101); three were left-handers and two were retrained left-handers.

Table 1. Participants' demographic characteristics.

Group		**NHI**	**Main PWA**	**Inter-rater PWA**	**Test-retest PWA – 1**	**Test-retest PWA – 2**
N		106	85	20	20	20
Gender	**F/M**	77 / 29	26 / 59	7 / 13	8 / 12	11 / 9
Age (years)	**M (SD)**	49.9 (18.4)	57.6 (12.1)	57.1 (11.5)	54.9 (10.3)	58.5 (12.9)
	Range	19 - 86	25 - 80	32 -70	34 - 69	39 - 82
Time post-onset (months)	**M (SD)**	NA	34.7 (45.2)	55.3 (71)	53.1 (37.1)	38.2 (35.7)
	Range	NA	1 - 249	2 - 249	12 - 162	8 - 133

Note. NHI – neurologically healthy individuals; PWA – people with aphasia. Inter-rater PWA group included randomly selected participants from the Main PWA group for evaluation of the test's inter-rater reliability. Test-retest PWA - 1 group included additionally recruited participants for evaluation of test-retest reliability; they completed all subtests except discourse comprehension, sentence production, and discourse production. Test-retest PWA group - 2 included additionally recruited participants who performed discourse comprehension, sentence production, and discourse production subtests.

Age stratification

Initially, the data were collected to evenly represent three age groups: 18-39 years old (group 1, *N* = 33), 40-59 years old (group 2, *N* = 36), and 60+ years old (group 3, *N* = 37). After the data were collected, we tested for significant differences between the three age groups of the NHI cohort in each subtest (Kruskal-Wallis test and post-hoc Dunn's test with Holm's multiple comparison adjustment were used). Only group 3 differed significantly from the other two groups, while no significant differences were observed between groups 1 and 2. Thus, based on the statistical differences between the groups, we pooled groups 1 and 2 together, which resulted in two age cohorts: young (18-59 years old; *M* = 39.3, *SD* = 13.1; *N* = 69) and elderly (60+ years old; *M* = 69.7, *SD* = 6.6; *N* = 37).

Main PWA group

All PWA except one were recruited at the Center for Speech Pathology and Neurorehabilitation, Moscow, Russia. None of them had history of neurodegenerative disorders or substance abuse. There were 85 participants in the PWA group (see Table 1 for demographic characteristics); 44 participants were in the young (age: *M* = 49.1, *SD* = 10.3) and 41 in the elderly age cohorts (age: *M* = 66.8, *SD* = 4.8). The level of formal education varied from incomplete secondary school (8 years) to a university degree (typically 15 years), with the majority of the participants (58.8%) having some form of higher education degree (12-15 years). Most participants were premorbidly right-handers (*N* = 80); one was left-handed, one – a retrained left-hander, and three were ambidextrous.

All the PWA had speech and language deficits due to focal brain damage of various etiology confirmed by a CT or an MRI scan. Most participants had damage to the left hemisphere

(*N* = 82); two had bilateral damage; one had combined damage to the left hemisphere and the vertebrobasilar area. The majority of the PWA (*N* = 77) had a single or recurrent stroke (ischemic or hemorrhagic); six had traumatic brain injury (TBI); one had impairments due to tumor resection (meningioma); and one had a complex etiology (TBI + infection + toxic). All were diagnosed with aphasia after a standard clinical examination by a certified speech pathologist or neuropsychologist. Depending on the type of aphasia the patient was classified as either having a fluent or a non-fluent type of aphasia, or determined non-classifiable in the cases when the type of aphasia could not be identified unambiguously (see Table 2) according to the aphasia classification by Luria [3,4,30]. Additionally, for all the PWA except one individual a clinically established comprehensive language battery, the ASA [5] (described in detail in the Introduction) was also administered, which provided an overall score reflecting general severity of language impairment.

Table 2. Fluency groups determined according to Luria's classification of aphasia in the main PWA group.

	Age group		
Fluency groups	***Young***	***Elderly***	***Total***
Fluent	13	23	36
Non-fluent	23	13	36
Non-classifiable	7	4	11
NA	1	1	2

Note. For NA cases, no full record of neuropsychological examination is available.

Inter-rater PWA group

For the analysis of inter-rater reliability, we randomly selected 20 individuals from the main aphasia group who completed all the subtests (see Table 1 for participants' demographic characteristics). Because comprehension subtests were scored automatically (see description below), we evaluated inter-rater reliability only for the subtests targeting expressive language (repetition and production).

Test-retest PWA group

To evaluate test-retest reliability, the RAT was administered to 20 PWA with chronic aphasia (not included in the main aphasia group) on two separate occasions. The two testing sessions were on average 25.3 days apart (*range* = 14-47; *SD* = 9) with no treatment provided between sessions. Due to a technical error, data for three subtests (discourse comprehension, sentence production, and discourse production) were not recorded. To evaluate test-retest reliability of the abovementioned subtests, we recruited additional 20 PWA with chronic aphasia (again, not included in the main aphasia group) and tested them on these three subtests on two separate occasions (two testing sessions were on average 9.3 days apart; *range* = 4-18; *SD* = 4.1). Demographic characteristics for these two PWA groups are presented in Table 1.

All participants (PWA and NHI) gave their informed consent to participate in the study. The study was approved by the Committee on Interuniversity Surveys and Ethical Assessment of Empirical Research of the HSE University.

Rationale and development of the RAT

General structure of the test

The RAT is composed of three main parts: *auditory comprehension, repetition,* and *oral production*. Within each domain, individual subtests target processing at different language levels including phonological, lexical-semantic, syntactic, and discourse. *Auditory comprehension* is assessed at different levels of linguistic analysis with the following subtests: nonword discrimination, auditory lexical decision, single word comprehension of nouns and verbs, sentence comprehension, and discourse comprehension. This hierarchical set of subtests allows to determine the language level(s) at which comprehension breaks down. The *repetition* subtests include: nonword, word, and sentence repetition – and are designed to evaluate integrity of sublexical and lexical pathways for repetition, along with auditory short-term memory capacity. The *oral production* subtests encompass naming of objects and actions, sentence production with syntactic priming, and picture-elicited discourse production. This selection of subtests helps to distinguish between impairments in production at the lexical-semantic and syntactic levels, and to assess these abilities cumulatively under relatively natural conditions (in discourse production), enabling detection of mild residual deficits in expressive language abilities.

Within each subtest, (psycho)linguistic variables known to impact language processing in PWA are systematically manipulated to ensure inclusion of items of varying difficulty and to provide detailed information about intact and impaired components of the language system. Where applicable, item selection was based on relevant psycholinguistic parameters of the verbal and pictorial stimuli (imageability, age of acquisition, name agreement, image agreement, object / action familiarity, visual complexity: http://en.stim-database.ru, [31–33]; lemma frequency [34]). The manipulation of critical (psycho)linguistic variables helps to dissociate PWA's difficulties at specific linguistic levels more accurately. Additionally, matched stimuli across some of the subtests allow for a direct comparison of PWA's performance across tasks and domains. Specifically, the items in the single word comprehension subtests were matched with the items in the naming subtests on a number of psycholinguistic parameters. Additionally, the sentence comprehension and production subtests employed similar syntactic constructions. See Table 3 for a brief description of the subtests' design and supporting information for a comprehensive account and a detailed rationale behind their construction (see S1 File).

All visual stimuli accompanying different RAT subtests consisted of black-and-white line drawings. For single-word comprehension and naming subtests, pictures were taken from the Database of Russian Verbs and Nouns [31–33]. The visual stimuli for the sentence comprehension and production subtests, and the picture for the discourse production subtest were specially created for the RAT by the same artist. Auditory stimuli for all the subtests were recorded in a studio by a professional male speaker.

Table 3. Description of the RAT subtests.

Domain	Subtest (levels evaluated)	Task (# items)	Factors manipulated	Example in Russian (English translation; type of stimuli)
AUDITORY COMPREHENSION	Nonword discrimination (phonological)	Listen to pairs of nonwords and identify whether they are the same or different n = 22	• Consonant distinctive features (manner, place of articulation, voicing, palatalization) • Target position (initial, final) • Syllabic structure (VC, CV, CVC, CCVC, CVCC, CCVCC)	• "ро" /ro/ - "ло" /lo/ (manner of articulation, initial, CV) • "друф" /druf/ - "труф" /truf/ (voicing, initial, CCVC)
	Lexical decision (lexical)	Listen to sound strings and identify which of them are real words n = 24	• Lexical status: words (only low frequency, concrete words) vs. nonwords based on real words • Length (2 vs. 3 syllables long)	• "кенгуру" (kangaroo) (word) • "дловарь" /dlɐˈvarʲ/ (nonword based on the word "словарь" /slɐˈvarʲ/ (dictionary); analogous to dictionary → mictionary)

Domain	Subtest (levels evaluated)	Task (# items)	Factors manipulated	Example in Russian (English translation; type of stimuli)
	Single word comprehension: nouns & verbs (lexical-semantic)	Listen to the word and match it with one out of four pictures Nouns: n = 24 Verbs: n = 24	• Part of speech (nouns vs. verbs) • Frequency • Relationship between the target and the distractors (phonological, semantic, unrelated) • Items in noun and verb comprehension matched on psycholinguistic parameters • Matched on the same psycholinguistic parameters with the items in the naming subtest	• Nouns: “ракета” (rocket - *target*) – “космонавт” (astronaut - *semantic distractor*) – “ракетка” (racket - *phonological distractor*) – “мяч” (ball - *unrelated*) • Verbs: “петь” (sing - *target*) – “танцевать” (dance - *semantic distractor*) – “пить” (drink - *phonological distractor*) – “есть” (eat - *unrelated*)
	Sentence comprehension (syntactic)	Listen to the sentence and match it with one out of two pictures n = 24	• Construction type (simple active constructions, subject and object relative clauses, prepositional constructions) • Word order (canonical vs. noncanonical) • Semantic reversibility (reversible vs. irreversible)	• “Где мальчик спасает девочку?” where boy.NOM rescue.PRS.3 girl.ACC (Where is the boy rescuing the girl?) (simple, canonical, reversible) • “Где мальчик кладет в сумку колбасу?“ where boy.NOM put.PRS.3 in bag.ACC sausage.ACC (Where is the boy putting the sausage in the bag?) (prepositional, noncanonical, irreversible)
	Discourse comprehension (discourse)	Listen to a story and verify a set of statements about events/details n_{texts} = 1 $n_{statements}$ = 16 (8 pairs, statements within a pair refer to the same story element)	Type of statements: • relation to the story (plot-focused vs. detail-focused) • type of information (explicit vs. implicit) • veracity (true vs. false)	[Pair 1] • “Наташа приготовила еду, чтобы взять ее на озеро” (Natasha made food to take it to the lake) (plot-focused, explicit, true) • “Наташа приготовила еду, чтобы пригласить в гости соседей” (Natasha made food to invite the neighbors over) (plot-focused, explicit, false) [Pair 2] • “На берегу озера растет большое дерево” (There is a big tree on the shore of the lake) (detail-focused, implicit, true) • “На берегу озера совсем нет деревьев” (There are no trees on the shore of the lake)

Domain	**Subtest (levels evaluated)**	**Task (# items)**	**Factors manipulated**	**Example in Russian (English translation; type of stimuli)**
				(detail-focused, implicit, false)
REPETITION	Nonword repetition (phonological)	Listen to nonwords and repeat them back n = 24	• Wordlikeness (high vs. low) • Length (1, 3 and 5 syllables long) • Number of articulatory switches (0 to 5)	• “мариация” /mərʲɪatsɨjə / (based on the word “вариация” /vərʲɪatsɨjə /(variation), analogous to variation → mariation) (high-wordlikeness, 5-syllable long, 2 articulatory switches) • “исхофа” /ɪshofə/ (low-wordlikeness, 3-syllable long, 3 articulatory switches)
	Word repetition (phonological, lexical)	Listen to words and repeat them back n = 24	• Frequency (high vs. low) • Length (1, 3 and 5 syllables long) • Number of articulatory switches (0 to 5)	• “территория” (territory) (high-frequency, 5-syllable long, 1 articulatory switch)
	Sentence repetition (lexical-semantic)	Listen to sentences and repeat them back n = 12	• Sentence length (3 vs. 6 content words) • Frequency of lexical items (high vs. low)	• “Машина опять не работает” (The car is not working again) (short, high-frequency condition) • “Капризная барышня критикует чудной цветочный орнамент” (The capricious baroness criticizes the intricate floral ornament) (long, low-frequency condition)
ORAL PRODUCTION	Naming: objects & actions (phonological, lexical-semantic)	Name objects or actions depicted in the picture Objects: n = 24 Action: n = 24	• Part of speech (nouns vs. verbs) • Frequency (high vs. low) • Items in object and action naming matched on psycholinguistic parameters • Matched on the same psycholinguistic parameters with the items in the single word comprehension subtest	• Objects: “кровать” (bed) • Actions: “вырезать” (cut out)
	Sentence production (lexical-semantic, syntactic)	Describe the picture according to the provided spoken model (syntactic priming paradigm) n = 24	• Construction type (simple active constructions, subject and object relative clauses, prepositional constructions) • Word order (canonical vs. non-canonical) • Semantic reversibility (reversible vs. irreversible)	• [Prime] “Невесту везет жених” bride.ACC give ride.PRS.3 groom.NOM (The bride is given a ride by the groom), [Target] “Дедушку кормит девочка” grandfather.ACC feed.PRS.3 girl.NOM (The grandfather is fed by the girl) (simple, non-canonical, reversible) • [Prime]

Domain	Subtest (levels evaluated)	Task (# items)	Factors manipulated	Example in Russian (English translation; type of stimuli)
				"Девушка кладет авоську в сумку" gorl.NOM put.PRS.3 string bag.ACC in bag.ACC (The girl is putting the string bag in the bag) [Target] "Девочка кладет бочку в коробку" girl.NOM put.PRS.3 barrel.ACC in box.ACC (The girl is putting the barrel in the box) (prepositional, canonical, reversible)
	Discourse production (lexical-semantic, syntactic, discourse)	Produce a story based on the presented picture with exposition, climax and resolution. n = 1		

Implementation of the RAT on a tablet

We created a custom Android-based tablet application for automatic stimuli presentation and response registration for all RAT subtests. The application was developed using Java SE 8 programming language and can be installed on touch-screen tablets running an Android OS (4.2 and higher). Performance on the comprehension subtests (selection of a visual stimulus matching the auditory stimulus or selection of a yes/no response) is registered and scored automatically by the application. Reaction times are also registered for comprehension subtests; however, they were not analyzed within the present study and are not currently used for diagnostic purposes. Response accuracy and reaction time for each trial for comprehension subtests can be downloaded as .csv files for subsequent analysis. Oral responses to repetition and oral production subtests are recorded automatically for each trial separately and can be downloaded as .3gp files and analyzed manually.

Administration of the RAT

The RAT was presented on the Samsung Galaxy Tab A (model SM-T585) or Tab 4 (model SM-T531) tablets. Both tablet models had a screen size of 10.1 inches and the following screen resolution: 1920 x 1200 and 1280 x 800 pixels, respectively. While the test can be administered and scored in a traditional paper-and-pencil format (a paper-copy version of the stimulus cards and the scoresheets in Russian are available at – https://www.hse.ru/en/neuroling/research/rat/), the reported data were collected using the electronic version of the test. The whole test took 1-2 hours to administer (depending on the patient's aphasia severity). The NHI group completed the test in one session; the PWA required 1-3 testing sessions (depending on the fatigue levels) within the same week to complete the test.

All the subtests started with presentation of written instructions on the tablet screen. The examiner read them aloud and provided additional explanations if necessary. The instructions were followed by several practice items (typically three). Here, the examiner ensured that the participant understood all the instructions, repeating the practice items multiple times and providing feedback and clarifications, if needed. After clarifying all the questions, the actual test items were presented. For all the subtests, the visual stimulus appeared first and was followed (where applicable) by the auditory stimulus with a 2-second delay. For the comprehension subtests, the next trial was automatically triggered upon response selection. For the repetition and production subtests, the examiner manually advanced to the next trial once the participant provided a verbal response. Participants' responses on the repetition and production subtests were not time-limited, although the examiner urged the participants to provide a response in case of a prolonged hesitation. If they failed to do so, the examiner proceeded to the next item and the item was marked as no response (incorrect). A single repetition of the test item upon request was allowed and incurred no penalty. No meaningful cues from the examiner were permitted. Sometimes for psychological reasons (e.g., to minimize a participant's frustration), it was necessary to repeat the stimulus item multiple times or provide a cue; however, subsequent responses were not scored, and the item was marked as incorrect. If the subject was unable to complete the entire subtest due to the persistent difficulties with performance, the remaining items were marked as incorrect.

Scoring guidelines

For the comprehension subtests, each response was automatically registered as correct or incorrect. As stated above, a single repetition of the item was allowed. The correct items gained a score of 1, incorrect – a score of 0; the total raw score was the sum of the item scores.

The recorded verbal responses in the production and repetition subtests were downloaded from the tablet to a computer, transcribed and scored manually according to subtest specific criteria (see below). Self-corrections in the repetition and production subtests entailed no penalty, but only the last verbal response was scored (even if the original response was correct). Additionally, verbal responses were not marked down for typical dysarthric distortions.

In the single word repetition subtests, a score of 1 was given for a correctly repeated item (nonword/word), 0.5 for a phonological paraphasia, and 0 for all other types of errors. In the sentence repetition subtest, each word in the sentence was scored separately in a similar fashion and the scores were summed up; there was also a penalty (-1) for omitted words and altered word order. The total raw score was the sum of the item scores.

In the naming subtest, a correct response was scored as 1, and all error types as 0. In the sentence production subtest, each sentence was evaluated according to four criteria: consistency with the prime, grammaticality, lexical-semantic adequacy, and other aspects of phrase appropriateness. A score of 1 was given if a criterion was met, and 0 if it was not. The sum of the scores on the four criteria constituted the score for a particular item; the total raw score was the sum of the item scores. Performance on the discourse production subtest was rated on a 5-point scale (with higher score corresponding to better performance) on each of the four criteria: fluency, grammatical complexity, paraphasias, and informational content. The total raw score for this subtest was the sum of the scores on the four scales.

Finally, subtest accuracy was defined as the percentage of correct responses out of the maximum possible score for all the scored items. As a measure of overall language impairment, we computed the General Aphasia Quotient (GAQ). It is used to determine presence and severity of aphasia and is calculated as an average of total percentage scores for all the subtests. Thus, it ranges from 0 to 100%. GAQ can be calculated only if total scores of all the subtests are available (i.e., all the subtests were administered to the participant, fully or partially).

More comprehensive explanation of the scoring procedures for each subtest are provided as supporting information in the detailed description of the RAT subtests (see S1 File). Prospective users of the RAT are encouraged to follow the same administration and scoring guidelines to ensure the validity of results.

Data analysis

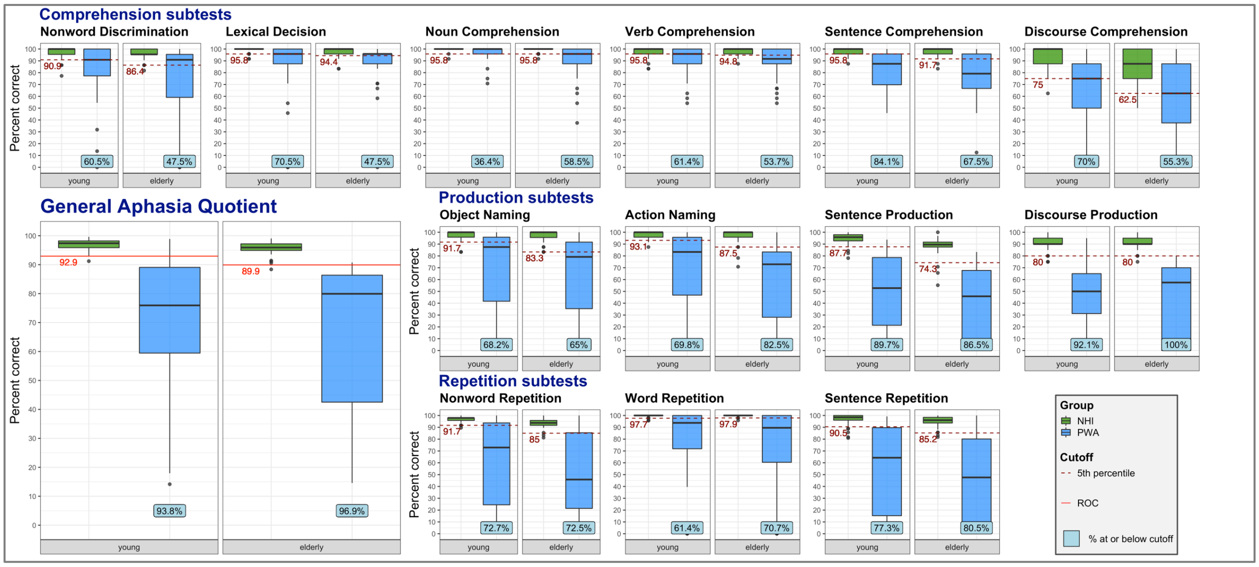
We established the following psychometric properties of the test based on the NHI and PWA data (all statistical analyses were done in R [35] and figures were drawn in ggplot2, ver. 3.3.2 [36]):

1. *Cut-off values* indicating impairment for both individual subtests and the overall score (GAQ) were determined. For individual subtests, the 5th percentile of the respective control group was used as the cutoff. To determine a cut-off value for the presence of aphasia, the Receiver Operating Characteristic (ROC) curve analysis was performed using the GAQ of the NHI and the PWA groups.
2. *Severity ranks* (mild, moderate, severe) for each subtest and GAQ were established based on percentile ranges of the PWA group.
3. *Concurrent validity* of the test was ascertained by correlating the GAQ based on the RAT with the overall scores on the ASA [5].
4. *Construct validity* was evaluated based on correlation patterns between the RAT subtests.
5. *Inter-rater and test-retest reliability* of the test was determined using inter-class correlations.

Results & discussion

Overall performance

Descriptive statistics for each subtest scores and GAQ for the NHI and PWA for both age cohorts are provided as supporting information (see S2 Table). Additionally, accuracy scores for each subtest for the two participant groups across the two age cohorts are presented as boxplots in Fig 1.



[**Fig 1. Accuracy subtest scores and the General Aphasia Quotient (GAQ) for the control group of neurologically healthy individuals (NHI) and the main group of people with aphasia (PWA) for each age cohort.** The box represents the interquartile range, with the central line marking the median. The whiskers denote the largest/smallest values within 1.5 times the interquartile range above/below the 75th/25th percentile. Values falling outside of that range are shown as black points. Red lines indicate cutoff thresholds: dashed for each subtest, representing the 5th percentile of the control group, and solid for the GAQ cutoff, determined according to ROC-curve analysis. The cyan box with percentages represents percent of PWA performing in the impaired range (at or below cutoff for normal performance for a given subtest).]

The distribution of scores clearly demonstrates that the NHI group performed near ceiling in most subtests, apart from Discourse Comprehension, Discourse Production, and Sentence Production. This lack of a ceiling effect in these specific subtests could be due to the complexity of these tasks and participants' variability in non-linguistic pragmatic skills (Discourse Comprehension, Discourse Production) and memory (Discourse Comprehension, the priming component of Sentence Production). Additionally, the two age cohorts in the NHI group performed comparably, except for subtests targeting phonological processing and/or memory (independent-samples two-tailed Welch t-tests: Discourse Comprehension, t = -3.47, p = .001; Nonword Repetition, t = -4.17, p < .001; Sentence Production, t = -4.01, p < .001; and borderline significant for Sentence Repetition, t = -3.01, p = .0039), with significance value Bonferroni-corrected to p = .05/13 = .0038. This reflects typical patterns observed in the aging population due to increasing sensory deficits, declining working memory and general slowing [37,38].

Performance of individuals with aphasia was more variable, especially for repetition and production subtests, reflecting different language profiles and severity of the main PWA group (Fig 1). As expected, PWA obtained significantly lower scores across all subtests compared to the NHI group in both age cohorts (based on independent-samples two-tailed Welch t-tests with significance value Bonferroni-corrected to p = .05/26 = .0019*).* Two exceptions were Noun Comprehension in the young group and Lexical Decision in the elderly group, where the difference trended towards significance (p = .003 in both cases). To determine the effect of fluency, an independent-samples two-tailed Welch t-test was performed between fluent (N = 36) and non-fluent groups (N = 36). No significant differences (p > .05) in any subtest were revealed, underscoring the prevalence of various linguistic deficits irrespective of aphasia group and the importance of detailed linguistic diagnostics.

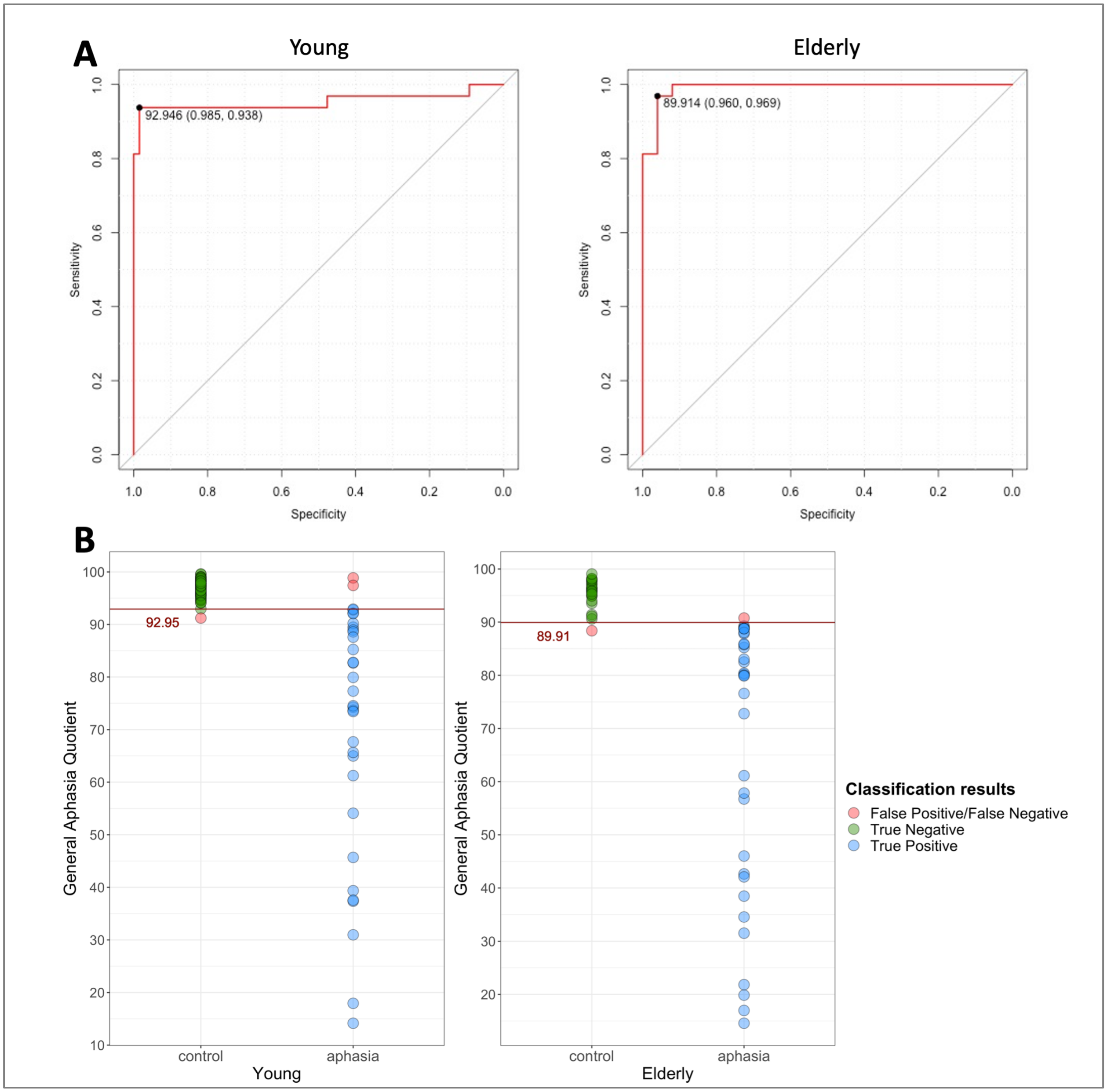
Establishment of cutoff values and the RAT's sensitivity and specificity

Cutoff values were determined differently for the subtests and for the GAQ. To calculate subtest cutoffs, we first removed outliers in the NHI group, defined as subtest scores lower than 90 percent and more than three deviations away from the mean value of the respective age cohort. This minimized the influence of single aberrant values on the cutoff criteria. Overall, one to two outliers were removed in several subtests in both the young and the elderly NHI cohorts. Next, for each individual subtest, the 5th percentile of the NHI group's score was calculated separately for the two age cohorts, which was considered the cutoff for impaired performance (see Fig 1). Performance at or below cutoff was considered abnormal, since 95% of healthy controls without a language impairment scored higher (cf., CAT [24]). The only exception to this rule was the Noun Comprehension subtest for the young cohort. In this one subtest, the 5th percentile equaled 100%, hence the cutoff for impaired performance was adjusted to the next score possible – 95.83% (23 out of 24 trials). Otherwise, even a score of 100% would be labeled as impaired. For percentages of PWA with abnormal performance on each subtest in two age cohorts see Fig 1. It should be emphasized that while a score at or below the cutoff indicates a deficit in a given task, it does not by itself imply presence of aphasia. The latter is ascertained based on the GAQ.

To determine the diagnostic cutoff for the GAQ, a ROC-curve analysis was performed separately for each age cohort using the pROC package [39]. A ROC graph is a visual representation of a classifier where true positive rate (sensitivity, i.e. classifying a PWA as a PWA) is plotted against false positive rate (1 – specificity, i.e., classifying an NHI as a PWA) and thus demonstrates the trade-off between the two. A ROC-curve is a step function where performances of the classifier for the same dataset but at different threshold values are plotted [40]. Based on the ROC-curve, a threshold (cutoff) value can be selected that optimizes both sensitivity (positive identification of those with aphasia) and specificity (correct negative identification of those without the disorder).

In our case, two ROC-curves for two age cohorts were generated (see panel A in Fig 2). For convenience, the x-axes of the graphs were flipped to plot sensitivity against specificity. For this analysis, outliers were not removed, because the GAQ represents an average score across all subtests and is, therefore, not detrimentally impacted by aberrant values in individual subtests scores. Also, we wanted to account for a full range of possible performance in calculation of the aphasia cutoff. The optimal threshold was selected to maximize the sum of sensitivity and specificity [41]. A GAQ score at or below the cutoff indicates presence of aphasia.

Two separate cutoff values for the GAQ indicating presence of aphasia were determined: 92.95% for the young cohort and 89.91% for the elderly cohort (see Fig 1), reflecting minor challenges the elderly control group experienced with some of the subtests. The RAT demonstrated excellent diagnostic accuracy: sensitivity was .938 for the young and .969 for the elderly cohort, while specificity was .985 and .96, respectively. Three and two individuals were incorrectly classified as control instead of aphasia or aphasia instead of control group in the young and elderly cohorts, respectively (see panel B in Fig 2). The missed aphasic diagnoses included two patients with very mild residual aphasia and one patient with anomic aphasia of traumatic etiology. Overall, this substantiates high sensitivity and specificity of the RAT, with its diagnostic accuracy comparable to other tests that used ROC curve analysis to determine aphasia cutoff (cf., QAB [22]).



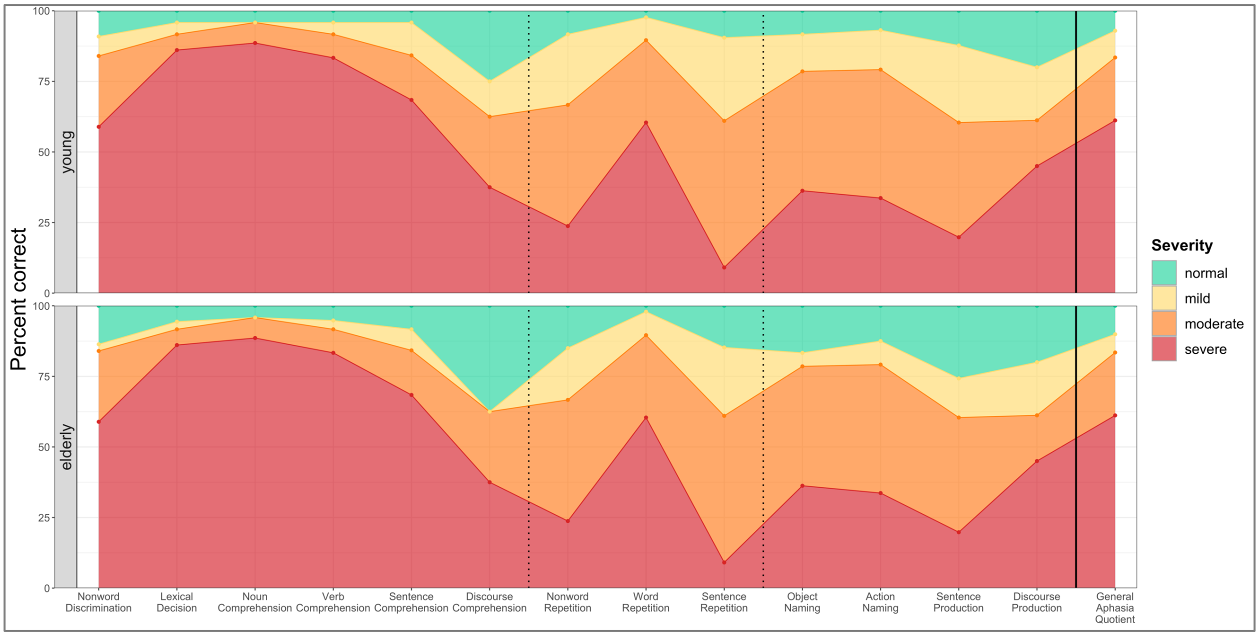
[**Fig 2. Determining the cutoff score for identification of aphasia.** Panel A – ROC-curves used to determine the GAQ cutoff score for the two age cohorts, with the x-axes flipped to plot sensitivity against specificity. The optimal threshold was selected to maximize the sum of sensitivity and specificity, as indicated by the black point on the graph. Panel B – classification accuracy for the two age cohorts according to the GAQ cutoffs.]

Determination of impairment severity

We empirically defined three impairment severity ranks (mild, moderate, and severe) for each subtest and for the GAQ based on the PWA data. To find the relevant ranges, we first selected, for each subtest and for the GAQ, the PWA with abnormal performance at or below the cutoff. Then the two age cohorts were combined in order to increase sample size and to ensure that the calculated ranges were not influenced by our two age cohorts being unbalanced in terms of aphasia types (see Table 2 in the Methods section). Next, we divided the accuracy scores into three approximately equal ranges by calculating the 34th and the 67th percentiles of the subtest scores / GAQ values for these combined groups. Specifically, for both the RAT subtest scores and GAQ values the three severity ranks were defined as the following, where X_i is the individual participant's accuracy score on a given subtest/GAQ:

- Mild: 67th percentile ≤ X_i ≤ cutoff;
- Moderate: 34th percentile < X_i < 67th percentile;
- Severe: 0 ≤ X_i ≤ 34th percentile.

Performance above cutoff was considered normal. See Fig 3 for severity ranges for subtest accuracies and the GAQ, and supporting information for respective values (see S3 Table).



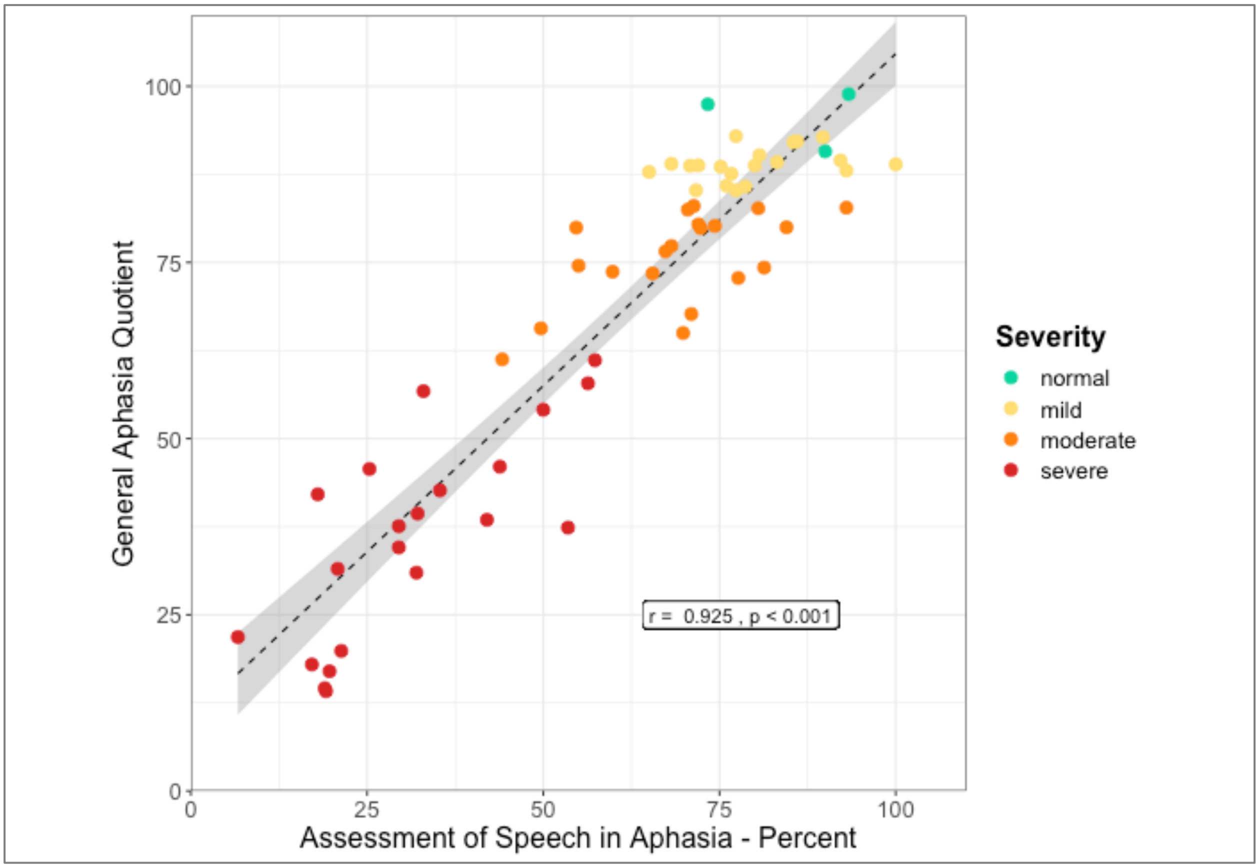
[Fig 3. Severity ranks for subtest accuracy scores and the GAQ for the two PWA age cohorts.]

As can be clearly seen from Fig 3, comprehension subtests, where PWA typically score higher (except for Discourse Comprehension), had narrower moderate and mild ranges, while for repetition and production tasks these ranges were more evenly distributed. This most likely reflects several factors: Comprehension subtests being easier due to their design (multiple-choice vs. open-ended questions for repetition/production), and comprehension abilities being more spared in aphasia in general. Accordingly, as the Discourse Comprehension subtest had a safeguard built in against guessing (i.e., to receive credit, participants had to respond correctly to two questions pertaining to the same part of the story), the severity ranges were less skewed towards the higher accuracy values. In other words, individual subtests were not (and probably could not) be equated for difficulty. This makes direct comparison of raw accuracy scores between subtests uninformative, making the appraisal of severity ranks across subtests more relevant. Also, from Fig 3 it can be inferred which subtests posed the most difficulty for our aphasia sample (where lowest accuracy scores corresponded to the threshold for severe level of impairment): Discourse Comprehension, Nonword Repetition, Sentence Repetition, Object and Action Naming, and Sentence Production.

Overall, we determined these severity ranks primarily for clinical purposes. Attributing a corresponding severity level of impairment to participant's performance on each subtest allows clinicians to compare different subtest scores and clearly identify spared and impaired language domains. Additionally, it allows to track the patient's progress between different time points.

Concurrent validity

Concurrent validity of the RAT was established by correlating the GAQ with the overall scores on the ASA [5]. A strong Pearson correlation was observed ($N = 64$, $r = .925$, $p < .001$), substantiating the validity of the test (see Fig 4). However, the data also show that individuals with similar ASA total scores could obtain substantially variable GAQ scores, e.g., the same ASA score may correspond to normal, mild, or moderate impairment based on the GAQ score. This suggests that RAT provides a more differentiative evaluation of language deficits in aphasia, as it covers additional language domains (repetition), includes further language comprehension tasks (Nonword Discrimination, Lexical Decision), and affords more fine-grained assessment of language production at the sentence and discourse levels.



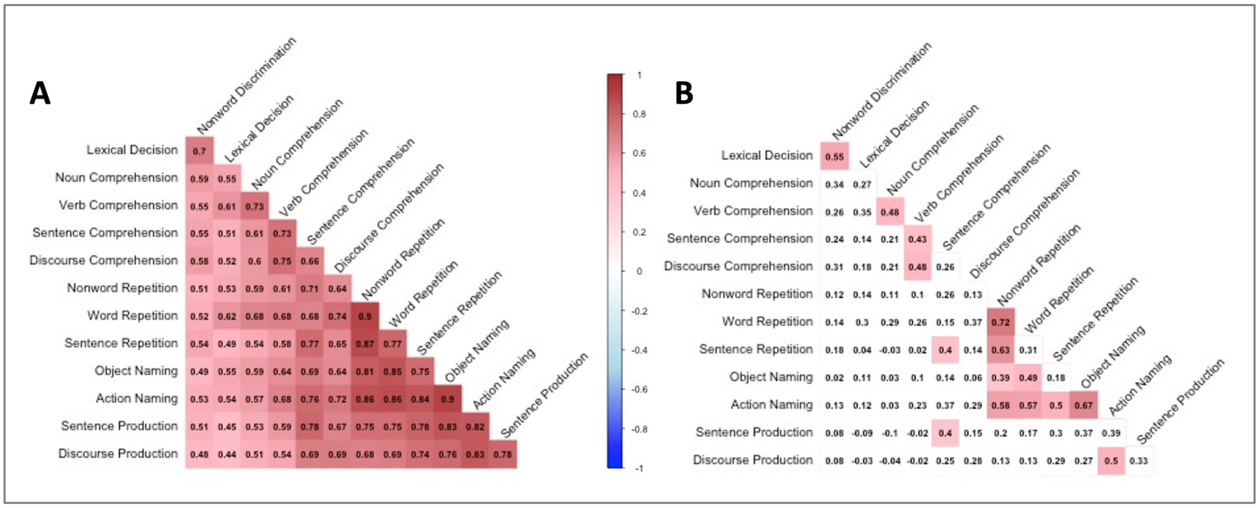
[**Fig 4. Correlation between the GAQ and the total score on the Assessment of Speech in Aphasia (ASA), a widely used aphasia battery in Russian.** Different colors indicate different severity ranks based on the GAQ.]

It should also be noted that those participants identified as having mild aphasia according to the RAT demonstrated a range of scores on the ASA, but that range also fell into the interval for moderate-to-mild level of impairment according to the ASA classification (73% - 87%). While it is beyond the scope of the present paper to contrast the two tests in detail, this observation most likely reflects greater impact of memory abilities on performance in the ASA comprehension subtests (as participants have to comprehend strings of words increasing in length), and possibly inter-rater reliability issues with scoring of sentence and discourse production tasks on the ASA.

Both factors lead to variability in scores on the ASA while the underlying language abilities remain unchanged.

Construct validity

Next, we explored the inter-relationships between the RAT subtests. Notably, significant and strong Pearson correlations (Bonferroni-corrected for all pairwise comparisons) between all subtest scores were observed (see Fig 5, A), as has been demonstrated previously for other language tests (QAB [22]; CAT [24]). We also performed a novel analysis that is not typically employed in aphasia batteries. We ran partial correlations (psych package for R [42]) between subtest scores accounting for aphasia severity as measured independently by the total score on the ASA [5]. Here, a more nuanced and domain specific pattern of correlations between subtests emerged after correcting for multiple comparisons (see Fig 5, B). Only associations between subtests that measured similar underlying language abilities (within and across linguistic levels) continued to show a significant association, underscoring that the subtests are measuring what they intend to measure and are differentially sensitive to different underlying linguistic impairments.



[Fig 5. Correlation between the subtests' scores. Panel A – simple Pearson correlations between the RAT subtests without accounting for aphasia severity. Panel B – partial Pearson correlations between the RAT subtests accounting for overall aphasia severity as measured independently by the total score on the Assessment of Speech in Aphasia (ASA). The plotted correlations are based on complete pairwise observations. The Bonferroni-corrected *p*-value equals .05 / 78 = 0.0006. Tiles with significant correlations are highlighted.]

Auditory comprehension subtests specifically targeting phonological and lexical levels (Nonword Discrimination and Lexical Decision) correlated only with each other and with no additional subtests. Single word comprehension subtests were also correlated. Interestingly, it was specifically verb comprehension that was found to be related to sentence and discourse level comprehension, supporting the idea of the role of the verb as a central sentence element. This correlation emerged even though most of the trials in the Sentence Comprehension subtest had syntactic but not semantic distractors. Accordingly, it is in line with the hypothesis that verb grammatical properties (e.g., argument structure) are processed during comprehension and production of isolated verbs [43], linking the impairment at the single-verb and sentence levels. A similar relationship was observed between Action Naming and Discourse Production, with correlation between Action Naming and Sentence Production trending towards significance. Generally, comprehension subtests were not related to repetition and production subtests, except for the sentence-level tasks. Performance on the Sentence Comprehension subtest was related to both Sentence Repetition and Sentence Production subtests, suggesting that their performance may be relying on the same underlying processes, e.g., short-term/working memory and syntactic processing.

Repetition subtests remained highly correlated; it should be noted that specifically Nonword Repetition correlated strongly with Sentence Repetition likely indicating critical involvement of the phonological buffer in both tasks. As expected, Object and Action Naming subtests were related. Both naming subtests were also related to Nonword and Word Repetition subtests, but again it was specifically Action Naming that was related to the Sentence Repetition subtest and the Discourse Production subtest. Overall, the prominent relationships observed between performance on subtests targeting verb processing and sentence/discourse level tasks highlights the importance of assessing verb comprehension and action naming in aphasia. Future studies are needed to explore these differential association patterns in greater detail.

Inter-rater reliability

Inter-rater reliability for repetition and production subtests was calculated based on 20 evaluations of PWA responses (the inter-rater PWA group, see Table 1 in the Methods section). Each subject's response was evaluated independently by two trained raters according to the detailed scoring instructions. Inter-rater reliability was not computed for the comprehension subtests since those subtests are scored automatically by the tablet-based application. The interclass correlation coefficients, absolute agreement (ICC, type A-1) for each subtest were calculated using package irr [44] and are shown in Table 4. The ICCs ranged from .833 (Discourse Production) to .994 (Object Naming). These ICC values indicate excellent inter-rater reliability for all subtests, according to the criteria defined by Cicchetti [45]. The relatively lower (although still excellent) reliability of the Discourse Production subtest is a consequence of the more subjective nature of the scoring system for this task and is comparable to (or even exceeds) the inter-rater reliability values reported for other discourse rating scales [46]. No significant differences were observed between ratings provided by the two raters (paired-sample t-tests, *p* > .05). Overall, these results demonstrate that with the provided scoring instructions, the RAT can be reliably scored by trained clinicians.

Table 4. Inter-rater and test-retest reliability of the RAT subtests based on the interclass correlation coefficients, absolute agreement (ICC, type A-1).

	Inter-rater reliability			***Test-retest reliability***		
RAT subtest	*ICC*	*Rater 1,* *mean score*	*Rater 2,* *mean score*	*ICC*	*Time 1,* *mean score*	*Time 2,* *mean score*
Nonword Discrimination	-	-	-	0.675	79.8%	88.0%
Lexical Decision	-	-	-	0.777	94.4%	95.6%
Noun Comprehension	-	-	-	0.205	97.5%	98.3%
Verb Comprehension	-	-	-	0.472	95.0%	94.2%
Sentence Comprehension	-	-	-	0.807	85.2%	82.7%
Discourse Comprehension	-	-	-	0.784	70.0%	76.9%

RAT subtest	*Inter-rater reliability*			*Test-retest reliability*		
	ICC	*Rater 1,* *mean score*	*Rater 2,* *mean score*	*ICC*	*Time 1,* *mean score*	*Time 2,* *mean score*
Nonword Repetition	0.987	64.9%	66.4%	0.938	71.5%	70.9%
Word Repetition	0.968	87.0%	86.0%	0.944	86.0%	87.1%
Sentence Repetition	0.997	53.8%	53.5%	0.955	60.4%	58.3%
Object Naming	0.994	77.6%	78.3%	0.937	65.8%	70.0%
Action Naming	0.975	73.4%	75.8%	0.878	62.6%	63.3%
Sentence Production	0.965	48.1%	49.7%	0.971	57.3%	59.8%
Discourse Production	0.833	57.0%	62.5%	0.71	75.5%	75.2%

Test-retest reliability

Test-retest reliability was calculated based on 20 additional individuals with chronic aphasia who were evaluated two times each on two separate occasions (the test-retest PWA groups, see Table 1 in the Methods section), with no speech-language therapy in between. The ICCs (type A-1) for test-retest reliability for each of the subtests (calculated again using package irr [44]) are presented in Table 4. All repetition and oral production subtests demonstrated excellent test-retest reliability according to the criteria in Cicchetti [45]. Comprehension subtests showed variable reliability: more complex subtests revealed excellent (Lexical Decision, Sentence Comprehension, Discourse Comprehension) and good (Nonword Discrimination) reliability, while the single word comprehension subtests demonstrated fair (Verb Comprehension) and poor reliability (Noun Comprehension). These low ICCs reflect high probability of responding at chance (i.e., limitations of a forced choice format) and the ceiling effects observed in these subtests (cf., CAT [24]). If compared directly, the differences in scores between the two testing sessions for any of the subtests were trivial and non-significant (paired-sample t-tests, *p* > .05). Taken together, these results demonstrate that the RAT scores are highly stable across test administrations, with possible minor fluctuations in comprehension scores.

Limitations

While the development and the introduction of the RAT into clinical practice presents a great advancement in comprehensive language assessment of Russian-speaking people with aphasia, the collected dataset has several limitations, which will need to be addressed by future investigations.

First of all, since technical errors precluded collection of test-retest data for all of the RAT subtests in a single sample, we could not establish test-retest reliability values for the overall test score – the GAQ. Since test-retest reliability of most of the RAT subtests is high, we anticipate that overall test reliability will be high as well, however this still needs to be empirically demonstrated.

Furthermore, we did not directly investigate sensitivity of the test to detecting a clinically meaningful change. Future studies that document behavioral changes with criterion-based tasks could inform the sensitivity of the test to detecting improvement (or decline) in language functioning and provide guidance to clinicians on how to interpret observed changes in the scores in a meaningful way. Regression-based approaches for determining clinically significant changes in the scores should also be explored in future work (e.g., [47]).

Another limitation of the current normative dataset is that we only collected data from individuals with stroke who were diagnosed with aphasia. Future inquiries need to include persons post stroke but without language impairments, so that sensitivity of the test specifically to language deficits rather than to general cognitive sequalae of the stroke (e.g., fatigue, compromised attention, memory, executive skills) is ascertained. While the selective relationships observed between different RAT subtests demonstrate that subtests are differentially sensitive to specific language deficits and underscore the test's construct validity, data from a non-aphasic stroke group would further raise the diagnostic value of the RAT.

Finally, the RAT currently does not assess reading and writing abilities. We hope that in the near future we will be able to develop and standardize these subtests as well.

Conclusions

The RAT is the first comprehensive aphasia language battery in Russian, sensitive to a range of deficits and with properly established validity, inter-rater and test-retest reliability according to contemporary psychometric standards. It provides a multidimensional characterization of impaired and spared aspects of language functioning at different linguistic levels in different domains: auditory comprehension, repetition, and oral production. By using a ROC-curve analysis (which is rarely done in aphasia tests, with the QAB [22] being a notable exception), we optimized the test's sensitivity and specificity to obtain excellent diagnostic characteristics across different age groups and aphasia types. Provided conversion of raw scores to severity ranks simplifies the test's interpretation in clinical use, enabling meaningful comparison across subtests, patients, and time points. Notably, the RAT is the first comprehensive aphasia test in any language to be fully automatized for presentation on a tablet, maximizing further standardization of administration and scoring procedures, simplifying data collection, and facilitating record-keeping. The most recent tablet-based version of the RAT has identical functionalities in terms of stimuli presentation and response registration to the original version described in the Methods, but also has a user-friendly interface for scoring all the subtests on the device, comparing scores to normative data and reporting. This greatly facilitates clinical work, as it obviates the need for manual computation of scores, and clinicians can easily see how the evaluated patient compares to the normative sample in each of the subtests and to their own previous performance. Also, we hope that our carefully documented experience in designing and standardizing a tablet-based comprehensive aphasia test will serve both as an example and an inspiration for development of psychometrically sound and automatized aphasia batteries in other languages.

Overall, the results of the current standardization study clearly demonstrate that the different subtests of the RAT were differentially sensitive to language deficits in aphasia, and that the test is a valid and reliable tool for Russian language assessment and aphasia diagnosis. We hope that the tablet-based version of the RAT will be widely used in clinical and research settings, leading to substantial improvement in aphasia management for Russian-speaking patients.

Acknowledgements

We are in debt to the late Prof. Shklovsky for his patronage of this endeavor throughout the years and facilitation of data collection. We thank Roman A. Cheremin for providing access to the resources of the Center for Speech Pathology and Neurorehabilitation, Moscow, Russia. We also thank Prof. Nina F. Dronkers who provided valuable advice during initial stages of the test development. We are grateful to Prof. Roelien Bastiaanse, discussions with whom inspired the sentence production scoring system. We thank Svetlana Kuptsova, Elena Ivanova, Victoria

Pozdnyakova, Tatiana Bolgina, Anastasia Samoukina, Anastasia Shlyakhova for their help with data collection. We acknowledge help from all the colleagues from the Center for Language and Brain of the National Research University HSE for their comments on earlier versions of the manuscript. As always, we are deeply grateful to participants for volunteering their time to make this work possible.

Funding

This work was supported by the Center for Language and Brain NRU Higher School of Economics, RF Government Grant, ag. No. 14.641.31.0004. MVI contribution was also supported by NIH/NIDCD R01-DC016345.

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Supporting information

S1 File. Detailed description of individual subtests of the RAT.

S2 Table. Descriptive statistics for accuracy subtest scores (% correct) of the RAT for the control group of neurologically healthy individuals (NHI) and the main group of people with aphasia (PWA) for each age cohort.

S3 Table. Cutoffs scores (%) and identified 34th and 67th percentiles for the PWA group used to determine aphasia severity ranks in each subtest and the General Aphasia Quotient (GAQ).