SPECIFIC FEATURES OF MEMORY CONSOLIDATION AND RECONSOLIDATION IN OLDER INDIVIDUALS WITH VISION AND HEARING IMPAIRMENTS

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Sensory impairments (visual and auditory) reduce quantity and quality of the information input. The associated memory loss can be classified as intrinsic decline in memory functionalities or mere physiological effect of sensory deprivation. This study aimed to specify this issue by analyzing memory consolidation and reconsolidation processes in older people with sensory deficits. The study enrolled 65–75 year-old individuals (n = 61) distributed into four groups: patients with unilateral sensorineural hearing loss (n = 17); patients with bilateral sensorineural hearing loss (n = 14); patients with visual impairment (n = 19); and patients with combined sensory deficits (n = 11). The methods included Luria's auditory-verbal ("10 words") and visual memory tests and Bartlett's experimental procedure. A decrease in memory volume for auditory-verbal and visual-figurative short-term memories was observed in all groups. The results reveal significant adverse dynamics of qualitative and quantitative indicators for memory consolidation and reconsolidation processes, associated with decreased volume of short-term memories, both auditory-verbal and visual-figurative. Based on these findings, we conclude that consolidation and reconsolidation efficiency depends on proper accommodation of the newly incoming information to already memorized modules (previous experience) and requires dosing of the newly incoming information in order to preserve its integrity at the stage of consolidation.

Keywords: visual-figurative memory, semantic memory, memory consolidation, memory reconsolidation, sensory impairments, old age

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ОСОБЕННОСТИ ПРОЦЕССОВ КОНСОЛИДАЦИИ И РЕКОНСОЛИДАЦИИ ПАМЯТИ ПРИ ЗРИТЕЛЬНЫХ И СЛУХОВЫХ НАРУШЕНИЯХ В ПОЖИЛОМ ВОЗРАСТЕ

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Сенсорные нарушения (зрительные, слуховые) ограничивают количество и качество поступающей информации. При этом существенные затруднения вызывает решения вопроса о том, что выявленное нарушение памяти является собственно нарушением памяти или обусловлено сенсорными дефицитами. В связи с поиском ответа на поставленный вопрос нами была сформулирована цель исследования. Целью исследования было изучить процессы консолидации и реконсолидации памяти у лиц пожилого возраста с сенсорными нарушениями. В исследовании участвовали пациенты в возрасте 65–75 лет (n = 61), разбитые на четыре группы: пациенты с односторонней нейросенсорной тугоухостью (n = 17); пациенты с двусторонней нейросенсорной тугоухостью (n = 14); пациенты с нарушением зрения (n = 19); пациенты с сочетанным сенсорным дефицитом (n = 11). В качестве методов использовали методики А. Р. Лурия «10 слов» и «Зрительная память», а также экспериментальную процедуру, предложенную Ф. Бартлеттом. Установлено снижение объема кратковременной слухоречевой и зрительно-образной памяти по всем группам испытуемых у пациентов пожилого возраста с сенсорными нарушениями. Достоверно показано изменение качественно-количественных характеристик процессов консолидации и реконсолидации памяти при сенсорных нарушениях. Данное изменение обусловлено снижением объема кратковременной памяти (как слухоречевой, так и зрительно-образной). Сделан вывод, что важными условиями повышения эффективности процессов консолидации и реконсолидации являются необходимость «подстройки» вновь поступающей информации к уже имеющейся в памяти (предшествующем опыте), а также необходимость дозированного снижения объема вновь поступающей информации с целью сохранения ее целостности на этапе консолидации.

Ключевые слова: зрительно-образная память, семантическая память, консолидация памяти, реконсолидация памяти, сенсорные нарушения, пожилой возраст

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The integration of subjective content of the mind and our picture of the world is provided by systemic diversity of memory types and processes. The age-related alterations in memory functionalities result from accumulation of neural and non-neural impairments.

A number of studies emphasize the relationship of sensory and cognitive impairments in older individuals [1–8].

In particular, some experts associate characteristic memory loss with age-related hearing impairment in older people [5]. One hypothesis attributes the effect to progressive social isolation in connection with the hearing loss. The Wisconsin Longitudinal Study (WLS) participants reported hearing problems with concomitantly reduced engagement in several types of social activity. The self-perceived hearing impairment was related to substantial decline in memory function. The authors further demonstrate that self-reported hearing loss and social isolation represent independent risk factors for memory loss in older people [5].

Memory, from the perspective of processes and types of its implementation and functioning, provides an important compensatory resource for a number of disorders, regardless of age.

A relationship has been established between subjective age-related hearing loss (SARHL) and the functioning of episodic memory [6]. The data indicate that self-perceived hearing loss may have an indirect effect on episodic memory through its negative impact on weekly social activity. The dysfunctional hearing narrows the scope of social interactions and communication, which may negatively affect cognitive performance.

The age-related hearing loss, which affects the ability to hear high frequencies, eventually leads to major difficulties in perception of sounds and speech comprehension, especially under non-optimal listening conditions [7]. The hearing loss can be partly compensated by the use of executive functions such as working memory. Though auditory and speech impairments have been closely associated with cognitive flexibility, in mild to moderate degree of hearing loss, the neural and behavioral features of working memory are usually preserved.

Four possible causative mechanisms linking hearing loss and cognitive decline have been described: 1) generalized pathological process that simultaneously affects hearing and cognitive functions; 2) a decrease in cognitive reserve due to hearing loss (reduced information sources, loss of cognitive integrity); 3) overexpenditure of cognitive resources in perception of auditory-verbal stimuli; 4) a combination of mechanisms 1 and 3, with certain structures affected by a pathological process and the intact areas and neural networks of the brain redirected to compensate for the lost auditory perception [8].

According to a concept proposed by K. V. Anokhin, memory as a process is carried out through memorization, which involves two stages (phases). The short-term phase is characterized by unabridged fixation of stored information (without losses and distortions of content) within a short time period. This labile phase of memory corresponds to retention of an information trace in the form of reverberation of nerve impulses. The long-term phase of memorization is characterized by a reduction in information volume during its subsequent long-term storage without changes (Fig. 1).

The long-term memory implies preservation of a trace through consolidation and associated structural changes. The new information is installed and preserved through formation and reinforcement of synaptic connections between neurons in particular contours. The concomitant formation of retrieval system allows extracting the information when appropriate, as well as reconsolidation of memories after “using” them (by reproducing the stored information). Every reactivation of particular memory, during which the information is extracted, must be followed by its active reconstruction, recategorization, and, ultimately, reconsolidation (repeated saving of the content). Each memory retrieval event is accompanied by replacement of the existing memory trace with new content (a modified version of the previous).

Sensory impairments (visual and auditory) significantly reduce the information input in terms of quantity and quality. The associated memory loss can be classified as intrinsic decline in memory functionalities or mere physiological effect of sensory deprivation. This study aimed to specify this issue by analyzing the processes of memory consolidation and reconsolidation in older people with sensory deficits.

METHODS

All interactions with participants were carried out on individual basis. All participants provided written informed consent for the study.

The cohort included 61 patients (28 men and 33 women) aged 65–75 years (mean age — 68.4 ± 2.12 лет) and not involved in labor activity for at least 3 years by the time of the study. The first group included 17 patients with unilateral sensorineural hearing loss (ICD-10 code H90.4: Sensorineural hearing loss, unilateral with unrestricted hearing on the contralateral side). The second group included 14 patients with bilateral sensorineural hearing loss (ICD-10 code H90.3: Sensorineural hearing loss, bilateral). The third group included 19 patients with visual impairment (ICD-10 code H52.1: Myopia — visual acuity reduced to –7 D), the fourth group included 11 patients with combined sensory deficit (unilateral sensorineural hearing loss with decreased visual acuity). All groups had balanced gender representation. Inclusion criteria were the lack of cognitive impairment (at least 23 points on the Mini-Mental State Examination scale, MMSE); higher education status; and continued non-involvement in labor activities.

The study included a preparatory step and three experimental procedures.

Preparatory step

This step involved assessment of somatic and neurological status by qualified physicians. The cognitive status was assessed using MMSE scale.

Experimental procedures

Assessment of short-term auditory-verbal and visual-figurative memory volumes

The short-term auditory-verbal memory volume was studied using “10 words” method introduced by A.R. Luria [9]. The patient was read a list of 10 semantically unrelated words denoting specific objects. After listening to the stimulus words, the patient was asked to to reproduce them. The procedure was repeated five times. The following indicators were recorded: the number of correctly reproduced stimulus words; the number of multiply repeated words in a single output; the number of added words. The volume of short-term visual-figurative memory was assessed using the "Visual memory" technique. The patients were presented with a table consisting of 16 cells. Each cell contained one contour image of a particular object (geometric

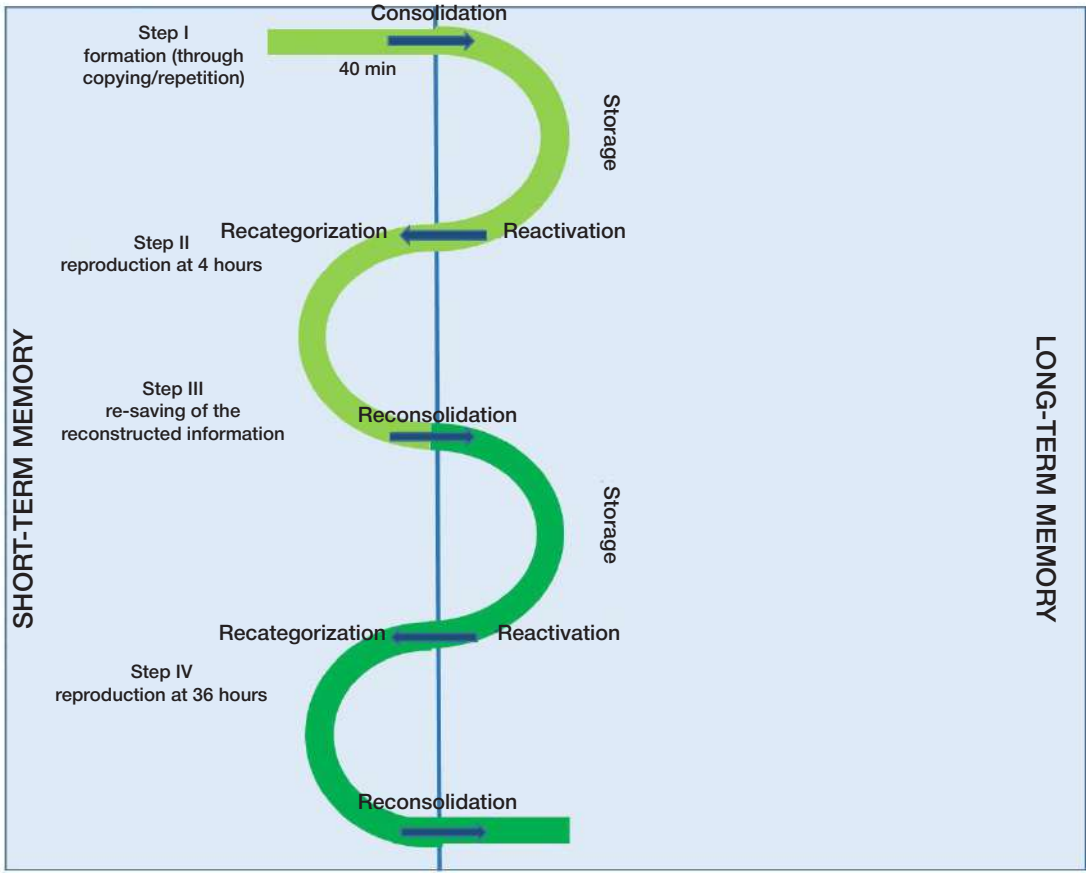

Fig. 1. Conceptual and experimental modeling of research on memory storage and retrieval

figures and schematic representations of objects). After 2 min presentation, the image was withdrawn and the patient was asked to recollect the depicted objects. The presentation was repeated five times and the same set of indicators was recorded after each presentation.

The next two experimental procedures were based on the F. Bartlett's experiments on reconstruction of memories by active retrieval.

Assessment of visual-figurative memory consolidation and reconsolidation processes

The patients were presented with symbolic image — a letter of ancient Greek alphabet resembling an owl (Fig. 2). An important condition of using it as a stimulus material was its absence in the previous experimental procedure.

The symbolic image (symbol) consisted of four parts: "head", "torso with leg", "wing", and "leg". Each of these parts contained distinct elements (for example, the "head" contained two elements — the outline and the inner "tick"). During presentation the participants were asked to copy the image as close as possible. After specific time periods (40 min, 4 h, and 36 h), the patients were given the following instruction: "Remember, we copied the image together? Draw it now, as you recollect it, as closely to the original as possible." The visual-figurative memory evaluation involved four criteria: the integrity of the produced images, the number of lost elements, the number of distortions, and the number of preserved elements.

Assessment of semantic auditory-verbal memory consolidation and reconsolidation processes

A text from the Indian epic of Canada, presented in Russian, containing 79 semantic units, 33 sentences, 1427 characters, and 295 words, was used as stimulus material. Semantic unit was defined as a grammatic entity bearing semantic content, with a core of a noun combined to other parts of speech (adjectives, verbs, and pronouns). The instruction

Table. Absolute ranges of short-term auditory-verbal and visual-figurative memory volumes in four groups of the study

Groups	Recollected series lengths (min–max)											
	1		2		3		4		5		40 min	
	AV	VF	AV	VF	AV	VF	AV	VF	AV	VF	AV	VF
Unilateral hearing loss	5–7	9–10	5–6	10–12	5–7	11–12	6–7	11–12	6–7	11–12	4–5	8–10
Bilateral hearing loss	5–6	8–9	5–7	8–10	5–6	9–10	5–6	9–11	4–6	9–10	3–6	8–9
Visual impairment	5–7	7–9	6–7	8–9	5–7	8–10	6–7	9–11	6–7	7–9	4–6	6–9
Combined sensory deficits	4–6	5–7	5–6	6–7	5–6	6–8	4–6	7–8	4–5	7–8	3–5	5–7

Note: AV — auditory-verbal memory; VF — visual-figurative memory.

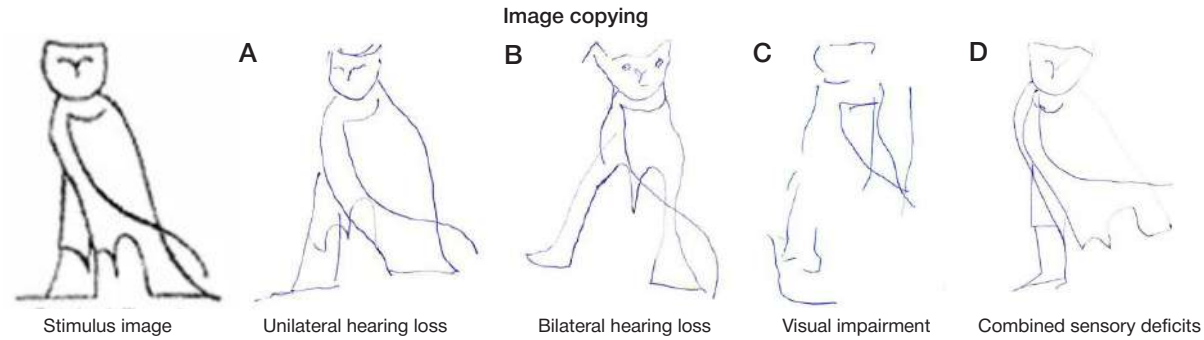

Fig. 2. Stimulus image presented in the redrawing tasks and its immediate copies produced by four groups of the study

ran as follows: "Now I will read you a text. Listen to it and retell the story as close to the text as possible". In 40 min, 4 h, and 36 h, the participants were asked to recollect and retell the text. The evaluation criteria included the number of preserved sentences, the number of preserved semantic units, the number of distorted sentences, the number of distorted semantic units, the number of confabulated sentences, and the number of confabulated semantic units. Categorization of semantic units distinguished object and trait (characterization of an object), object and time (who and when), object and action (who did what), object and place (who and where), as well as causal relationships. A semantic map was developed and used in data recording. Mistakes in the verbal recollection were categorized as substitutions and losses. The substitutions included distorted semantic units and confabulatory semantic units. The losses encompassed incoherent sentences lacking semantic content.

The quantitative data were processed using descriptive statistics (mean values, standard deviations) with nonparametric Mann–Whitney *U*-test and Wilcoxon *T*-test for pairwise comparisons at $p < 0.05$.

RESULTS

The preparatory step produced and verified the enrollment in four groups with distinctive neurological and somatic status.

The primary assessment of short-term memory volume during the first experimental procedure revealed a decrease for both auditory-verbal and visual-figurative modalities in all four groups of the study (Table).

Comparative assessment for the auditory-verbal and visual-figurative stimuli reproduction test performance in four groups of the study revealed no significant between-the group differences. The lowest indicators of short-term auditory

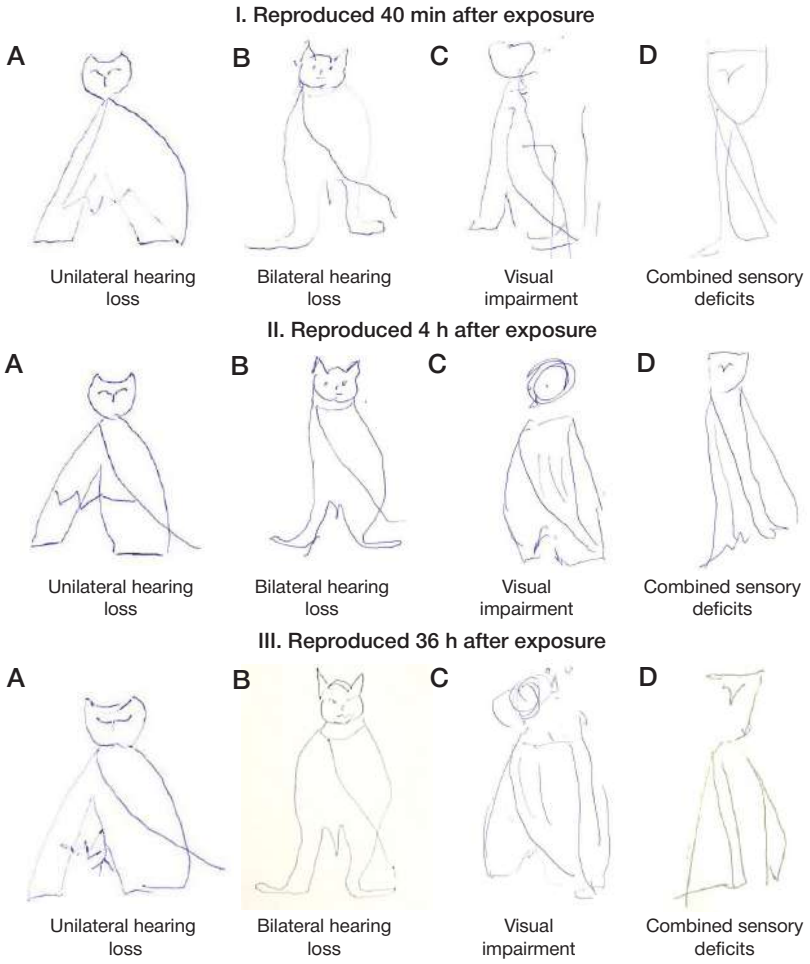

Fig. 3. Representative copies of the stimulus image made at different time points after exposure (40 min, 4 h, and 36 h) in four groups of the study

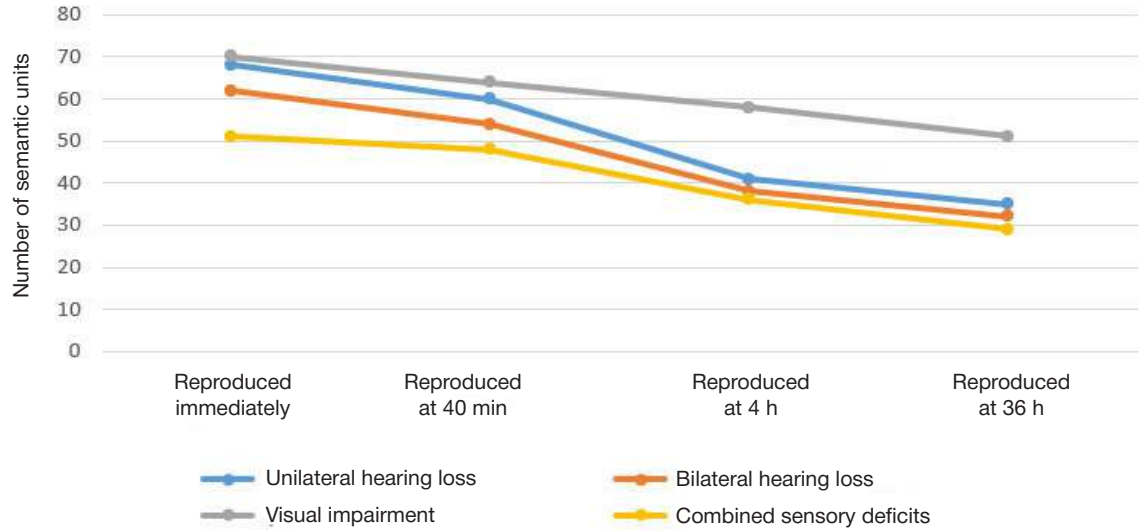

Fig. 4. Averaged profiles of correctly reproduced semantic units during auditory-verbal tasks in four groups of the study

memory volume were revealed in patients with bilaterally impaired hearing ($x \pm \sigma = 5.12 \pm 0.72$) and combined sensory deficits ($x \pm \sigma = 4.12 \pm 0.10$). The loss of original content for these groups was over 50%. The sensory deficiency of the auditory analyzer system leads to substantial loss and distortion of the incoming information already at the stage of perception. Patients with hearing impairments tend to introduce new words while reproducing the word series. For the visual-figurative modality, the lowest indicators of short-term memory volume were revealed in patients with combined sensory deficits ($x \pm \sigma = 7.19 \pm 0.22$) and visual impairments ($x \pm \sigma = 7.42 \pm 0.68$). The loss of original content for these groups was over 50%. The patients presented with characteristic substitutions of the initial visual-image stimuli by similar in size and shape (for example, a bed instead of a sofa; a ball instead of an apple; a dog instead of a goat; etc.). Upon memorization (2 minute exposure of a table with images), the depicted objects were correctly identified and named by all participants.

Experimental study of the auditory-verbal and visual-figurative memory consolidation and reconsolidation in four groups of participants revealed the following features. At the stage of copying (immediate redrawing) of the stimulus image, the maximum degree of similarity with the original, preserving all parts and elements of the symbolic image, was achieved in the group of patients with unilateral hearing loss (Fig. 2A). Corresponding images produced by patients with bilateral hearing impairment preserved the major parts of the stimulus image while distorting their elements; furthermore, the images clearly lent towards the creation of specific image — an owl with eyes and a beak (Fig. 2B). Patients with visual impairment or combined sensory deficits presented with distortion and compromised integrity of the image. In patients with visual impairment, the original image disintegrates into separate, non-interconnected lines (Fig. 2C, D). The observed transformation of symbolic image into figurative one at the stage of immediate copying of stimulus image, which reflects the short-term memory storage for subsequent consolidation, leads to initial fixation of a distorted image.

Upon reconsolidation of the figurative-symbolic information at 40 min, 4 h, or 36 h time points in patients with sensory disorders, the distortion of consolidated visual-figurative content was apparent in all groups of the study, regardless of the degree and modality of sensory deficits (Fig. 3).

Patients with unilateral hearing loss produced images with minimal distortions. Only after 36 h, patients of this group reduced the number of parts and elements while introducing specific figurative content (bird's paws with clearly drawn fingers) (Fig. 3-III-A).

In patients with bilateral hearing loss, at the stage of initial consolidation (immediate copying of a stimulus symbolic image), the symbolic image is transformed into a figurative replica, with the clearly drawn owl's beak, eyes, and ears). The recollected images produced at 40 min, 4 h and 36 h timepoints preserve the image specificity and detalization as an "owl". At the same time, the number and identity of major parts remains unchanged and corresponds to the original symbolic image. In addition, the reconsolidations performed at 40 min, 4 h, and 36 h time points revealed further simplification of the image by transformation into specific images available in previous experience, with a reduction in the number of elements.

The corresponding images produced by patients with visual impairments (wearing vision correction devices) have more profound distortions with compromised integrity of the image and its portions (Fig. 2C). At 40 min, the decay of the memory trace for initial stimulus is evident. The image becomes specific and totally loses its symbolic character. In the act of reconsolidation, the image acquires a holistic quality; it also contains additional lines and pencil strokes that are superimposed on the image. At 4 h, the patient reproduces a coherent image, which resembles neither the stimulus, nor its copy. During the consolidation process ensuring transition of the image into a long-term memory, the symbol acquires distinctive features of a bird. The patient gives up mechanical copying of the original (especially difficult given a sensory deficit), but recreates it as a new image coherent with the pre-existing experience.

The opposite effect is observed in patients with combined sensory deficits: immediate copy of the stimulus reveals characteristic features of a specific prototype character from the pre-existing experience (Fig. 2D). However, at 40 min, the reproduction shows ultimate disintegrity, with only the "head" preserved, while the "body" is represented by a bunch of disordered lines. This phenomenon can be explained by functioning of certain compensatory mechanisms, which allow the patient to endow the image with integrity based on the experience. Reproductions made at 4 h and 36 h reveal further decay — the loss of individual elements and simplification of the rest to a set of randomly interconnected pencil strokes.

Thus, during retrieval of visual-figurative information in older patients with sensory disorders, specification and detailing of

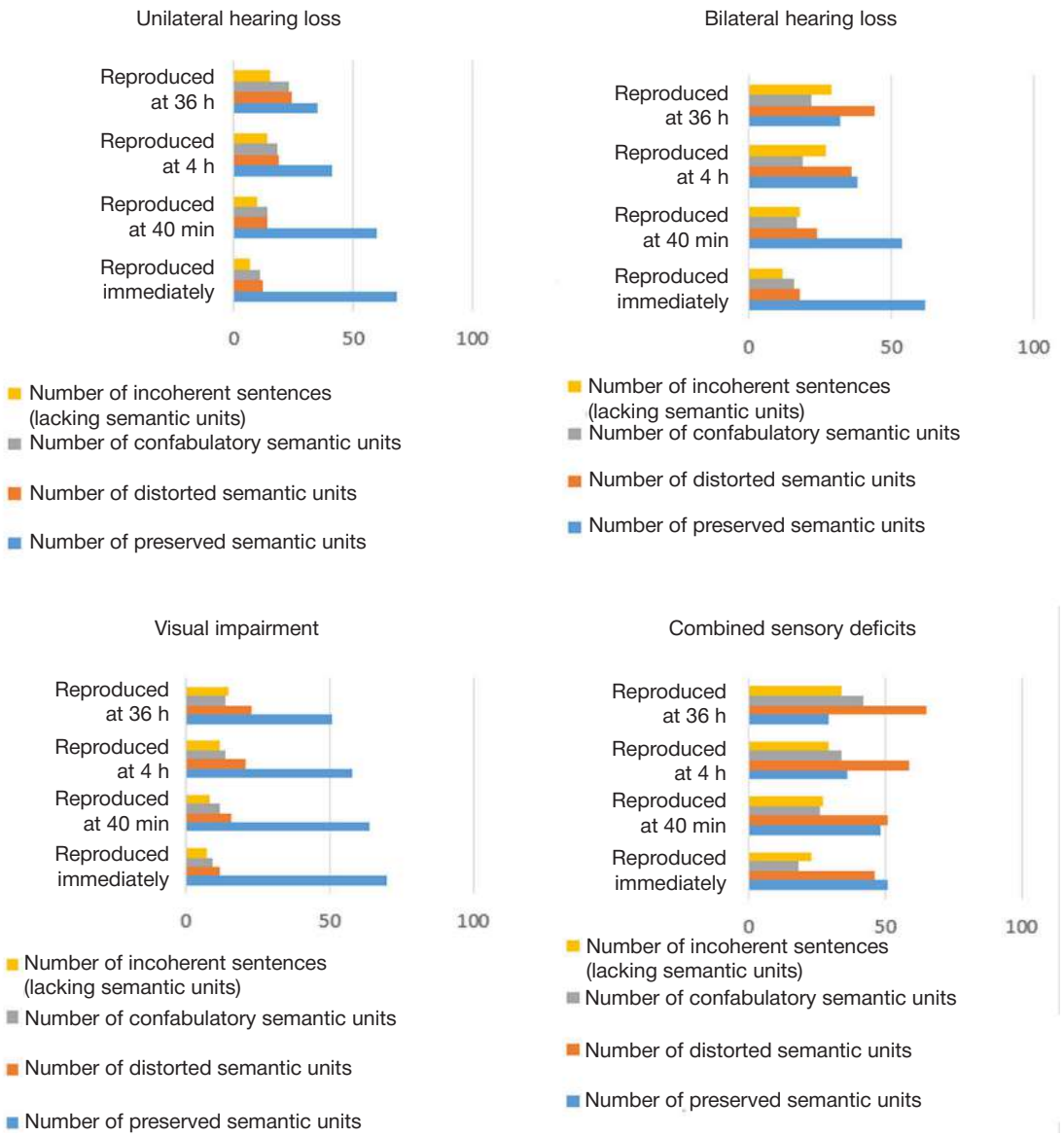

Fig. 5. Histograms of mean values for auditory-verbal memory indicators in four groups of the study

a stimulus image is fixed in accordance with the information available from a previous experience (reducing symbolic image to the image of an owl). Patients with hearing deficit produce integral images; patients with vision deficit produce images with characteristic complete disintegration of the visual-figurative content into two separate unrelated parts — the circumference of head and the "torso" with a set of extra strokes. (Figs. 3-II-C and 3-III-C).

Experimental assessment of the auditory-verbal memory consolidation and reconsolidation profiles of semantic recollection involved profiles of semantic recollection based on averaged counts of correctly reproduced semantic units during verbal recollection tasks (text retelling) in four groups of participants (Fig. 4).

Upon retelling of the text immediately after its auditory perception, the maximum loss of semantic content was observed in patients with combined sensory deficits, whereas the minimal losses of semantic content were observed in patients with visual impairment. Moreover, for patients with visual impairments, numbers of semantic units correctly reproduced at 40 min, 4 h, and 36 h were statistically similar. By contrast, significant decrease in numbers of correctly reproduced semantic units between 40 min and 4 h time points was revealed in groups of patients with unilateral hearing loss (p = 0.019), bilateral hearing loss (p = 0.021), and combined sensory deficits (p = 0.021). Significant between-the-group differences in the verbal reproduction quality (in terms of semantic content) were observed at 4 h only. At this time point, the number of correctly reproduced semantic units in patients with visual impairment was significantly higher compared with other groups including patients with unilateral hearing loss (p = 0.022), patients with bilateral hearing loss (p = 0.021), and patients with combined sensory deficits (p = 0.019). The analysis revealed no significant between-the-group differences for patients with unilateral hearing loss, bilateral hearing loss, and combined sensory deficits.

The analysis of counts and nature of the errors made during sequential rounds of auditory-verbal recollection at 40 min, 4 h, and 36 h, reveals a decrease in the number of correctly reproduced semantic units accompanied by an increase in the numbers of distorted and confabulatory semantic units, as well as the number of incoherent sentences of no semantic content, in all groups of participants (Fig. 5).

The study of auditory-verbal memory consolidation and reconsolidation processes in older patients with sensory disorders revealed specific patterns, notably a trend towards

schematization and concretization of the text. Another distinct trend was to change the sentence altogether with overall preservation of semantic units. The intrinsic semantic sense of the sentences was preserved better than the structure and specific wording. Overall, the recollections at different time points showed relative stability of the content compared with initial reproduction.

The patients with visual impairment typically revealed a higher degree of syntactic simplification; they also tended to use short sentences or fused several sentences into one if united by a single semantic topic. The patients with hearing loss presented with introduction of multiple details and excessive meticulousness of the stories. The excessive detail and verbosity in retelling was associated with loss of semantic content and often reduced the retelling to a dialogue with oneself regarding the correctness of what was heard: "...One night two young people went hunting from the settlement of Egulac to hunt seals. Seals? I don't think so. Why seals? This is somewhere in the southern latitudes. Weird. OK…"

DISCUSSION

The obtained results are consistent with the data presented by other authors [10–12]. Several studies relate a decrease in memorization volume to the inability of switching attention from actual psychological experiences to cognitive tasks. In such cases, objective impairment of mnestic functions may be missing or minimal (according to an objective neuropsychological examination). The observed decrease in volume of short-term auditory-verbal and visual-figurative memory in older individuals with sensory impairments manifests as distortion and partial loss of information in copying (redrawing) a symbolic image or immediate retelling of a story. The deficit leads to consolidation of the initially incomplete/distorted information, which is further modified upon subsequent retrieval from long-term memory during reactivation and recategorization with critical losses.

The observed decline in the qualitative and quantitative characteristics of memory consolidation and reconsolidation processes in older people with sensory impairments most probably involves a decrease in short-term memory volume (for both auditory-verbal and visual-figurative modalities). During the short-term phase of the memory process, the information is preserved without loss or content distortion for a short time period. Under conditions of significantly reduced short-term memory volume, experimentally proved in older patients with auditory and visual deficits, memorization operates with distorted and abridged mnestic representations. This labile phase of memorization involves complex reverberations of nerve impulses, the capacity which may also decline as a part of natural age-related changes in neurodynamics.

CONCLUSIONS

During reactivation of visual-figurative information in older patients with sensory disorders, specification and detailing of a stimulus image is fixed in accordance with the information available from a previous experience (reducing symbolic image to the image of an owl). Patients with hearing deficit produce integral images; patients with vision deficit produce images with characteristic complete disintegration of the visual-figurative content into two separate unrelated parts — the circumference of head and the "torso" with a set of extra lines. Patients with combined hearing and vision deficits lose individual elements: the image is simplified to several pencil strokes, partially interconnected. Such disintegration reflects the inability to represent the symbol in the internal speech plane through recategorization.

During reactivation of auditory-verbal information in older patients with sensory disorders, the information is critically simplified with compensation for the missing (lost) content by confabulations, semantically "empty" verbose sentences, and repetitions of simplified logical and grammatical constructions that do not correspond in semantic content to the original text.

The results of the study demonstrate the importance of accomodation of the newly incoming information to representations already stored in memory, effectively reducing its distortion upon consolidation and effectively preserving it during subsequent retrieval (extraction) and reconsolidation. At the same time, due to a decrease in the volume of short-term memory, in order to increase the efficiency of memory consolidation and reconsolidation processes, older patients with sensory impairments should be presented with new information in a dosed manner accounting for the reduced short-term memory volume. This mode minimizes the losses of newly incoming information at the stage of consolidation. Subsequent studies on memory consolidation and reconsolidation processes in elderly people with sensory impairments may focus on expanded age groups and nosological specifications of the patients.

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