LINGUO-SEMANTIC DESCRIPTORS OF PAINFUL SENSATIONS AS A MIRROR THERAPY EFFECTIVENESS CRITERION IN TRAUMA-RELATED AMPUTATION

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Assessment of phantom pain linguosemantic descriptors in patients with traumatic amputation during the use of mirror visual feedback is conditioned by the need to find criteria for the psychological phantom pain adjustment effectiveness. The study aimed to assess the dynamic changes in linguosemantic pain descriptors in patients with traumatic amputation showing manifestations of phantom pain syndrome as a criterion for evaluating the effectiveness of mirror visual feedback. The total sample size was 87 males post traumatic amputation of one lower limb (age 23–55 years). The research methods were as follows: Mini Mental State Examination (MMSE), original form for registering linguosemantic descriptors of phantom painful sensations, Visual Analog Scale (VAS) for phantom pain. The detected dynamic changes in linguosemantic descriptors of phantom painful sensations in patients with traumatic amputation of the limb showing manifestations of phantom pain syndrome during treatment involving the use of mirror visual feedback makes it possible to consider the following as effectiveness criteria: an increase in the number of pain descriptors represented mainly by concrete and tangible nouns (makes it possible to reduce phantom pain severity rated using a 10-point scale), as well as the increase in the number of descriptors that characterize non-painful unpleasant sensations at the linguosemantic level.

Keywords: manifestations of phantom pain syndrome, descriptors of phantom pain, linguistic and semantic descriptors, mirror visual feedback

Author contribution: equivalent.

Compliance with ethical standards: the study approved by the Ethics Committee of the Pirogov University (protocol No. 249 dated 17 March 2025) was compliant with the requirements of the Fundamentals of Legislation "On the Protection of Citizens' Health"; all subjects submitted the informed consent for assessment.

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ЛИНГВОСЕМАНТИЧЕСКИЕ ДЕСКРИПТОРЫ БОЛЕВЫХ ОЩУЩЕНИЙ КАК КРИТЕРИЙ ОЦЕНКИ ЭФФЕКТИВНОСТИ ЗЕРКАЛЬНОЙ ТЕРАПИИ ПРИ ТРАВМАТИЧЕСКОЙ АМПУТАЦИИ

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Изучение лингвосемантических дескрипторов фантомно-болевых ощущений у пациентов с травматической ампутацией в процессе применения зеркальной визуальной обратной связи обусловлено необходимостью поиска критериев эффективности психологической коррекции фантомно-болевых ощущений. Целью исследования было изучить динамику лингвосемантических дескрипторов болевых ощущений у пациентов с травматической ампутацией с проявлениями фантомно-болевого синдрома как критерия оценки эффективности зеркальной визуальной обратной связи. Общий объем выборки составил 87 мужчин, перенесших травматическую ампутацию одной нижней конечности (возраст — 23–55 лет). Методы исследования: краткая шкала оценки психического статуса MMSE, авторская форма регистрации лингвосемантических дескрипторов фантомно-болевых ощущений, визуальная аналоговая шкала (ВАШ) для оценки интенсивности фантомно-болевых ощущений. Выявленная динамика лингвосемантических дескрипторов фантомно-болевых ощущений у пациентов с травматической ампутацией конечностей с проявлениями фантомно-болевого синдрома в процессе терапии с использованием зеркальной визуальной обратной связи позволяет в качестве критериев эффективности рассматривать следующие: увеличение количества дескрипторов болевых ощущений, представляемых преимущественно в форме конкретных и вещественных существительных (позволяет снизить интенсивность выраженности фантомно-болевых ощущений, оцениваемой по десятибалльной шкале), а также увеличение количества дескрипторов, на лингвосемантическом уровне характеризующих неболевые неприятные ощущения.

Ключевые слова: проявления фантомно-болевого синдрома, дескрипторы фантомно-болевых ощущений, лингвосемантические дескрипторы, зеркальная визуальная обратная связь

Вклад авторов: равнозначный.

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The relevance of studying linguistic and semantic descriptors of painful sensations in patients with trauma-related amputation showing manifestations of phantom pain syndrome when using mirror visual feedback results from the fact that manifestation of phantom pain in patients with trauma-related amputation is, on the one hand, combined with manifestations of post-traumatic stress disorders, adjustment disorders, etc., and on the other hand the fact of having phantom pain manifestations affects and sometimes alters motivation for treatment in this group of patients. This impairs social and psychological adaptation, along with socialization in general in the long run [1]. According to the earlier research data, a large proportion of patients with amputations report severe manifestations of phantom pain, which requires special attention during psychological follow-up, rehabilitation training, and rehabilitation of such patients [2].

The mechanism underlying the phantom pain phenomenon is still a matter of debate. When considering the mechanisms underlying the emergence of phantom pain, four major groups can be distinguished formed based on the perceptual organization levels: peripheral, spinal, subcortical, and cortical mechanisms of phantom pain development [3] (Fig. 1).

At the peripheral level of perceptual organization the mechanism underlying the development of phantom painful sensations is determined by neuroma formation in the damaged area. Peripheral mechanisms can affect the processes occurring in the upstream structures, but do not cause phantom painful sensations [4]. At the spinal level of perceptual organization the emergence of phantom painful sensations results from alteration of the neuronal synaptic activity and involvement of nociceptive neurons due to the increased afferent innervation area. This leads to the formation of the abnormal algia system producing painful sensations. Furthermore, the activity of inhibitory neurons is significantly decreased, which interferes with the inhibition of afferent impulses transmitted to the brain [5, 6].

At the subcortical level of perceptual organization the mechanism underlying the development of phantom painful sensations is determined primarily by specific functioning of thalamic structures associated with amputation of any part of the body [7–9]. The thalamus can become sensitized due to the increase in the number of Na^+ channels in thalamic neurons (this has much in common with peripheral sensitization). As a result, pain sensitivity may increase again [9]. The cortical level is represented by three mechanisms underlying the emergence of phantom pain. The first mechanism is associated with functional alterations in the somatosensory and primary motor cortex resulting from the loss of any body part [10–15]. The second one is related directly to the processes associated with the body schema functions within the framework of the proprioceptive memory concept [16–20]. The third central mechanism underlying the development of phantom painful sensations is considered within the framework of the integrative model referred to as neuromatrix [14, 21, 22].

Regardless of the mechanisms underlying the development of phantom painful sensations, a unique role in psychological follow-up of patients with trauma-related amputation of the limb showing manifestations of phantom pain syndrome is played by subjective experiences of pain in the amputated limb. In addition to somatic (physical) sensations, subjective experience of pain is accompanied (characterized) by psychological perception of a physical defect, as well as the experience of traumatic situation of the limb amputation. Psychologically, the phenomenon of subjective experience of pain associated with the loss of the limb (phantom painful sensations) is determined as a combination of pseudo-sensory sensations developed post amputations and is manifested by the illusion of the presence of the body part lost [23–26]. Subjectively, the phantom painful sensations are described using the characteristics of their localization, nature (burning, twisting, sharp, etc.), as well as subjective intensity assessment.

Thus, subjective experiences of phantom painful sensations in patients with amputation of the limb represent a target for psycho-corrective interventions when dealing with this group of patients.

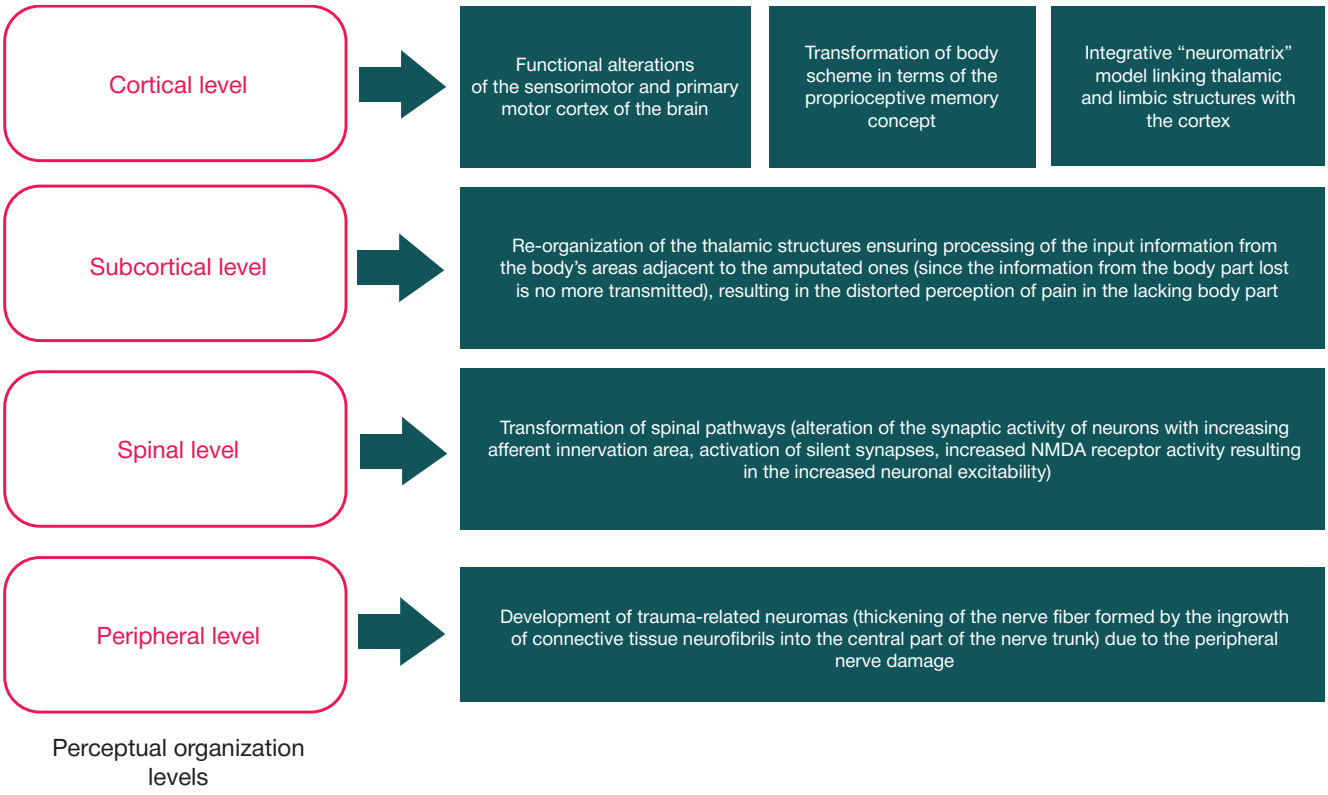

Fig. 1. Scheme hierarchical organization of the mechanisms underlying the emergence of phantom pain

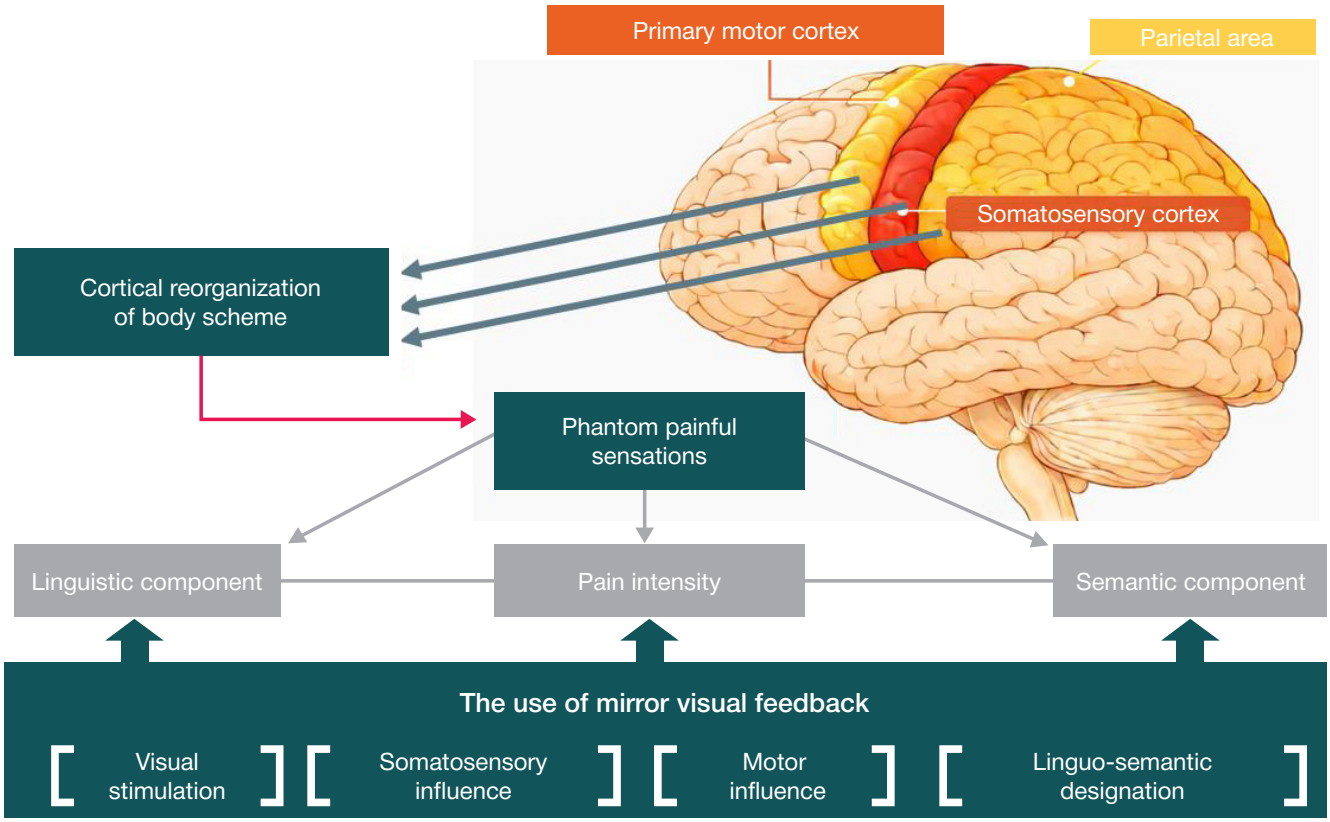

Fig. 2. Scheme of the conceptual model of the dynamic changes in linguistic and semantic descriptors of painful sensations in patients with trauma-related amputation of the limb showing manifestations of phantom pain syndrome during therapy involving the use of mirror visual feedback

In the today's practice of psycho-correction of the phantom pain syndrome manifestations, there is a wide variety of methods aimed at different targets and with different levels of evidence [27–30]. In this paper we will present the procedure of using the mirror visual feedback (mirror illusion) method during psycho-correction of phantom painful sensations, as well as the criteria to assess the procedure effectiveness.

V.S. Ramachandran was the first to propose the use of the mirror visual feedback (or mirror illusion) [13]. In the further studies conducted by both foreign (Deconinck F.J.A., Smorenburg A.R.P., Benham A., Ledebt A., Feltham M.G., Savelsbergh G.J.P., 2015; Zhang JJQ, Fong KNK, Welage N, Liu KPY., 2018) [31, 32] and domestic (Mokienko O.A., Bobrov P.D., Soloveva A.A., Isaev M.R., Kerechanin Ya.V., Ratnikova V.Yu. et al. 2025) [33] researchers, it has been reliably determined that the mirror visual feedback ensures activation of mirror neurons and motor structures of the brain in the hemisphere ipsilateral relative to the active arm, triggering activation of brain plasticity processes [31, 32]. These neurophysiological mechanisms provided the basis for mirror therapy [33]. The efficacy of using mirror visual feedback to adjust the phantom pain syndrome manifestations has been proven at the level of clinical (neurophysiological) manifestations [26, 31, 33]. However, there is no consensus on the criteria of the effectiveness of using this method to adjust manifestations of subjective pain experiences in patients with amputation of the limb.

Considering pathophysiological basis of the emergence of phantom painful sensations, it can be noted that during cortical rearrangement reported in specific cortical areas of the brain, during therapy involving the use of mirror visual feedback, the subjective experience of phantom painful sensations is transformed, which is manifested at the level of linguistic and semantic components (sensory linguistic descriptors and metaphorical constructs — representations of pain), as well as subjective assessment of their intensity. The mechanism underlying the effect of mirror visual feedback during therapy of phantom painful sensations is based on eliminating conflict between the visual and somatosensory afferentation (proprioceptive memory concept) and blocking maladaptive rearrangement processes in specific cortical areas (Fig. 2).

The phantom painful sensations occurring in patients with trauma-related amputation of the limb are designated and marked using the verbal (speech) means studied in linguo-semantic characteristics — descriptors. The linguo-semantic descriptors of phantom painful sensations are represented by various components: sensory descriptors, metaphorical constructs, affective-evaluative markers, and discursive strategies. The specifics of using linguo-semantic constructs to describe phantom painful sensations can include pain severity characteristics. The corrective effect of using mirror visual feedback is based on the fact that these components are influenced by visual stimulation, somatosensory effect, motor effect, and the linguo-semantic designation processes. The mechanism of the use of mirror illusion is based on eliminating conflict between the visual and somatosensory afferentation (proprioceptive memory concept) and blocking maladaptive rearrangement processes in specific cortical areas.

The study aimed to assess the dynamic changes of linguistic and semantic descriptors of painful sensations in patients with trauma-related amputation of the limb showing manifestations of phantom pain syndrome as a criterion to assess the effectiveness of using the mirror visual feedback.

METHODS

The study involved males aged 23–55 years post trauma-related amputation of lower limbs, presenting with phantom painful sensations. The sample size was 87 individuals post amputation

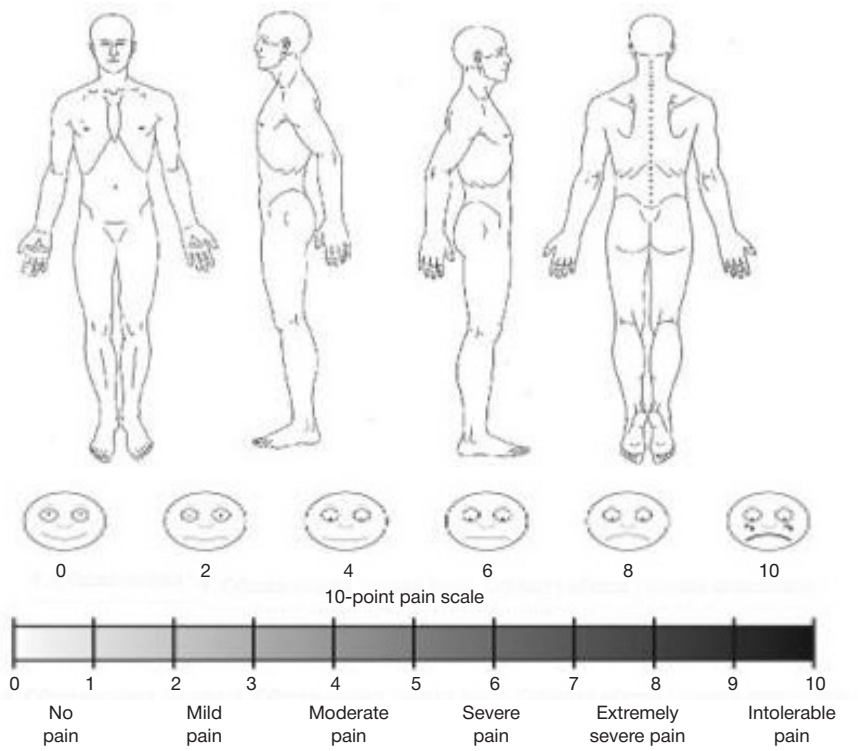

Fig. 3. Example form in the phase of psychological diagnosis of linguo-semantic descriptors of pain in patients with trauma-related amputation showing manifestations of phantom pain syndrome

of one lower limb (being through rehabilitation in a specialized medical institution, 6–18 months had passed since the date of amputation). All the respondents, who were through rehabilitation at the time of assessment, received pain management medications and physiotherapy prescribed by primary care physicians. Inclusion criteria: preserved cognitive function estimated using MMSE (Mini-Mental State Examination) — score 26–30 in quantitative terms. Exclusion criteria: postoperative period (post amputation of the limb); early recovery period (up to 6 months since the date of amputation); severe pain syndrome; other medical contraindications determined by a rehabilitation physician.

Research phases

A common form for recording of phantom pain manifestation was developed in order to implement the first (diagnostic) research phase. The form consists of four sections to be filled sequentially one after another, starting from the first one. At first, during the clinical interview, the patient named and recorded certain characteristics of phantom painful sensations (phantom pain descriptors), without limiting the number of those, and recorded the severity score (1–10 points) for each specified descriptor. Then he formulated and recorded a holistic image of pain (as a verbal description) in the form, and also noted pain severity on a scale ranging from 1 to 10. After that, he had to indicate the level of amputation of the lower limb on the body projections using a black pen, and then shade the regions of the amputated limb where phantom pain was localized with a blue pen. Furthermore, the regions of localization for the phantom pain descriptors recorded in the initial section of the questionnaire were marked with arrows in the body projections, adjacent to the shaded areas. At the final stage of filing the form, the patient had to assess the overall phantom pain severity using the Visual Analog Scale (VAS) and circle the number from 1 to 10 (Fig. 3).

The second research phase (phase of psychological correction) involved 40 patients, who were assessed by the rehabilitation physician and admitted to remedial classes before the psychological correction course involving the use of the FaBo mirror [34]. Among 47 patients, who were not involved in the phase of psychological correction using FaBo mirror, 21 individuals had pulled out; 26 individuals were not admitted to mirror therapy by a rehabilitation physician for medical reasons.

The algorithm for conducting training sessions is illustrated in Fig. 4.

Each patient with lower limb amputation attended five training sessions within the mirror visual feedback program for adjustment of phantom painful sensations.

The results obtained were quantified using the following methods: descriptive statistics (the mean, standard deviation, frequency analysis, mode, median, range) and comparative statistics (Wilcoxon signed-rank test, Fisher angular transformation, $p < 0.05$).

RESULTS

The relationship between the subjective phantom painful sensation severity estimates and the rates of selecting the descriptors to describe phantom painful sensations allowed us to reveal high variability in both the number of descriptors and the descriptor severity levels. However, the most common ones (central descriptors) are represented by three variants: “burning”, “shots”, and “tingling” (Fig. 5).

The rates of sensory descriptors in the group of war veterans with amputation of the lower limb are distributed as follows: “burning” (60%), “shots” (60%), “tingling” (46%), “nagging pain” (20%), “spasm” (16%), “throbbing pain” (6%), “freezing” (4%), “pulling pain” (12%), “itching” (12%), “twisting” (18%), “chills” (4%), “numbness” (8%), “compression” (12%), “dull ache” (6%), “shock” (10%), “lancinating pain” (6%). When comparing the rates of linguo-semantic descriptors with their intensity on a 10-point scale, discrepancy is reported: with the maximum rates of phantom painful sensations in the form of burning, shots, and tingling, the most intense are dull ache and the sensation referred to as “itching”.

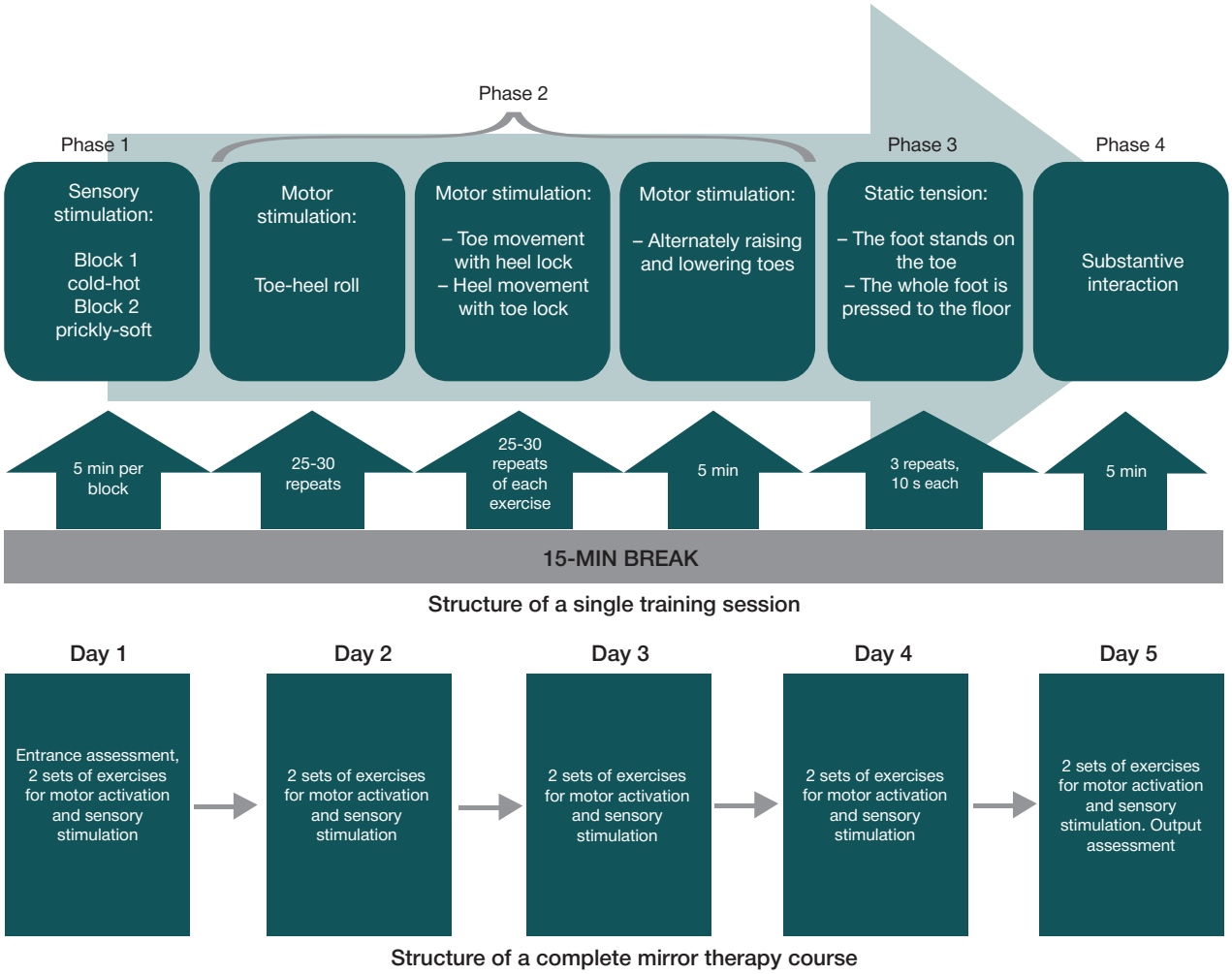

Fig. 4. Algorithm to conduct the psychological correction procedure involving the use of the FaBo mirror in patients with trauma-related amputation of lower limbs

We differentiate linguo-semantic descriptors of phantom painful sensations into two groups: the descriptors, the names of which are based on nouns, and the descriptors, the names of which are based on adjectives. The noun-based linguo-semantic descriptors are, in turn, divided into two groups: the descriptors designated by concrete and material nouns; the descriptors designated by verbal nouns. The share of the linguo-semantic descriptors represented by the adjectives describing qualitative characteristics of phantom painful sensations is 25%. The share of concrete and material nouns

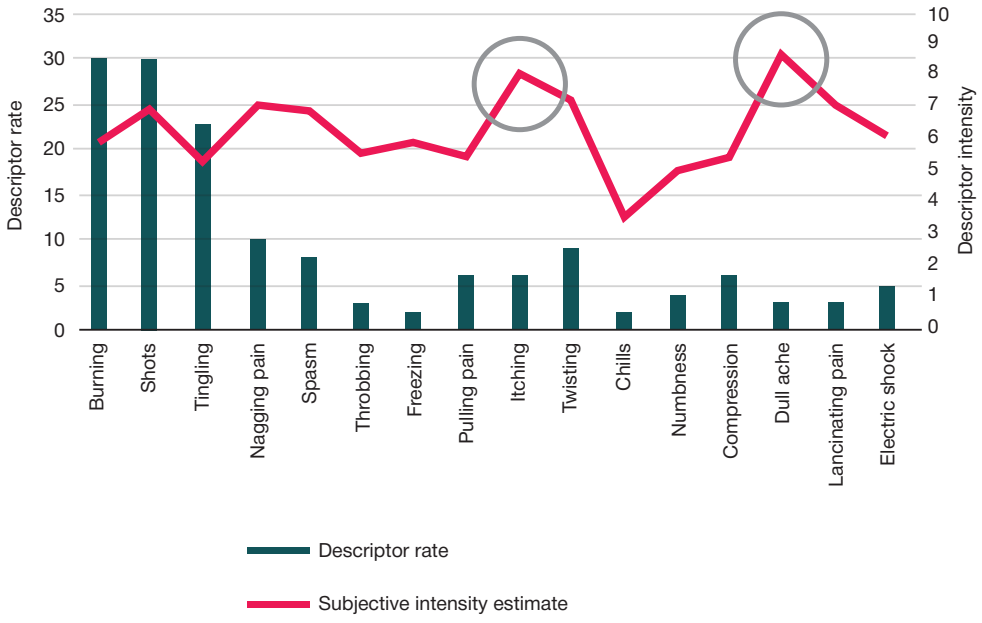

Fig. 5. Relationship between the rates of selecting the descriptors to describe phantom painful sensations and the subjective estimates of their intensity in patients

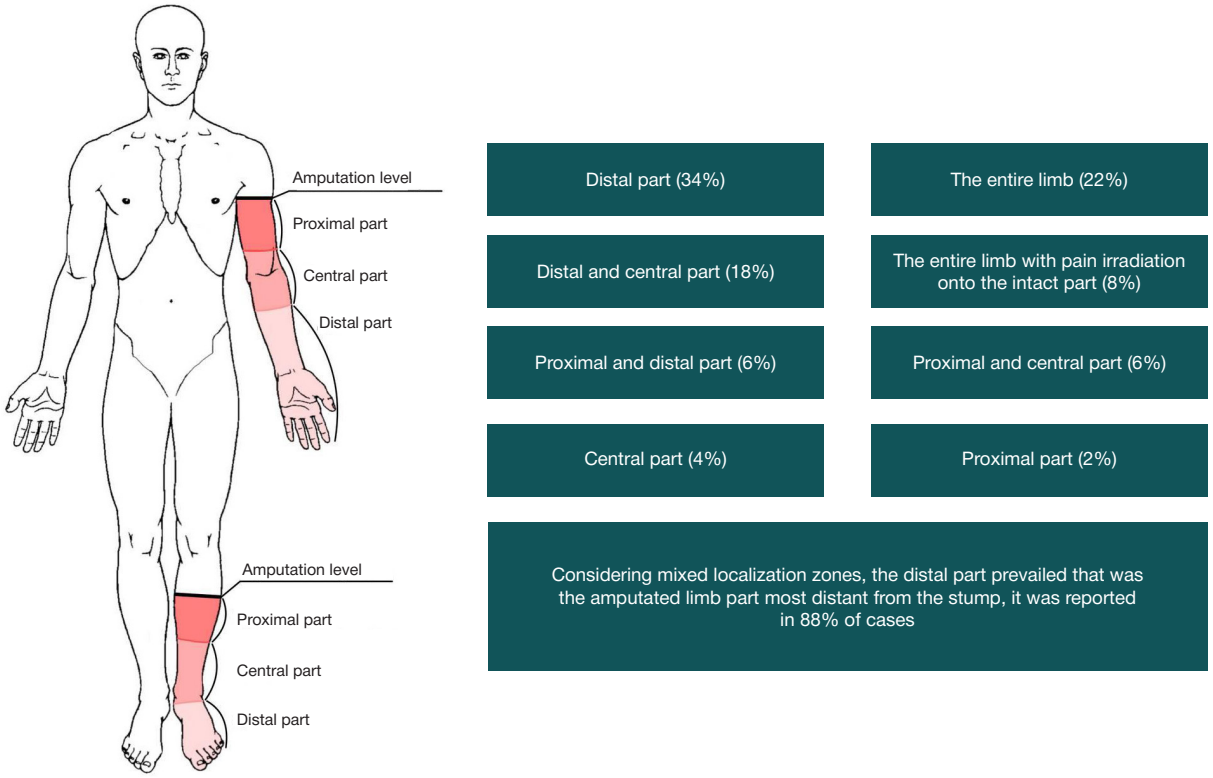

Fig. 6. Scheme of phantom painful sensation localization in patients with trauma-related amputation of lower limbs

characterizing individual meanings, personal meanings, and categorical structures of consciousness in designation of linguo-semantic descriptors is 31% of the total number of descriptors. The vast majority of descriptors are designated by patients with trauma-related amputation of lower limbs with verbal nouns, denoting the objectification of action. This linguo-semantic descriptor form, transforming the dynamic process into a static term, consolidates phantom painful sensations at the level of linguistic semantic meaning.

As for their qualitative characteristics, the descriptors were divided into two groups based on the criterion of painful nature: naturally, painful sensations predominate and account for 75% of the total number of descriptors (“burning”, “shots”, “tingling”, “nagging pain”, “spasm”, “throbbing pain”, “pulling pain”, “twisting”, “compression”, “dull ache”, “shock”, “lancinating pain”). The non-painful descriptors characterizing unpleasant sensations in the phantom limb that are not pain account for 25% and include such labels, as “freezing”, “itching”, “chills”, “numbness”.

The following trends are distinguished based on the subjective assessment of phantom painful sensation localization: in the distal part of the amputated limb — 34%, in the distal to central part of the amputated limb — 18%, the entire amputated part of the limb — 22%, the proximal to distal part of the amputated limb — 6%, the entire amputated part of the limb with the spread onto the intact part of the stump — 8%, central part of the amputated limb — 4%, proximal to central part of the amputated limb — 6%, proximal part of the amputated limb — 2% (Fig. 6).

According to the results of the painful sensation localization subjective assessment, the vast majority of patients with amputation of lower limbs specify the distal part of the amputated limb, which is most distant from the stump, — 88% of cases.

In addition to quantitative analysis, qualitative analysis was also carried out. The patients had to provide the description of a phantom painful sensation holistic image and estimate its subjective severity on a 10-point scale. A total of 88% of patients with phantom painful sensations were able to provide holistic images of pain. Three groups were formed based on the phantom pain image characteristics. The first group of images is characterized by involuntary movement of various parts of the amputated limb (in 61% of patients). The following speech constructs are used to describe the image of phantom pain sensations: “toes curl”, “toes are twisted”, “toes bend”, “the foot bends”, “the toes are stretching”. Clinical example: “the toes are intertwined and one of those digs its nail into the other and pierces it through”. The second group of images is characterized by changes in the size and integrity of the amputated part of the limb; it is represented in 20% of patients with amputation of lower limbs. When talking, the patients use such speech construct, as “the leg is swelling”, “a piece of meat was torn off”, “the nail digs into another toe”, “the leg has grown and is resting against the back of the bed”, “the nails are moving away from the toes”. Such representation of the holistic image of phantom painful sensations, as “the leg has grown and is resting against the back of the bed”, can be considered the clinical example. Patients of the third group represent the images through description of the exposure to the external stimulus (43% of patients). Such speech constructs, as “someone is pressing a bone on the skin”, “the toes are burnt with a lighter”, “the leg is in the water”, “the leg is clamped in a vice”, “the leg is pierced with an awl”, “an object falls on the foot”, were used to verbally describe the holistic image.

The correlation analysis procedure allowed us to distinguish two strategies of linguo-semantic designation of phantom painful sensations in patients with trauma-related amputation of lower limbs. The first strategy is determined by high differentiation of descriptors with their low intensity in terms of differentiation, but high aggregate intensity. This strategy is confirmed by the identified inverse significant correlations between the intensity of distinct linguo-semantic descriptors and the total number of descriptors describing phantom pain manifestations; as well as by the direct significant correlations ($r = 0.424$) between subjective estimates of the holistic image of

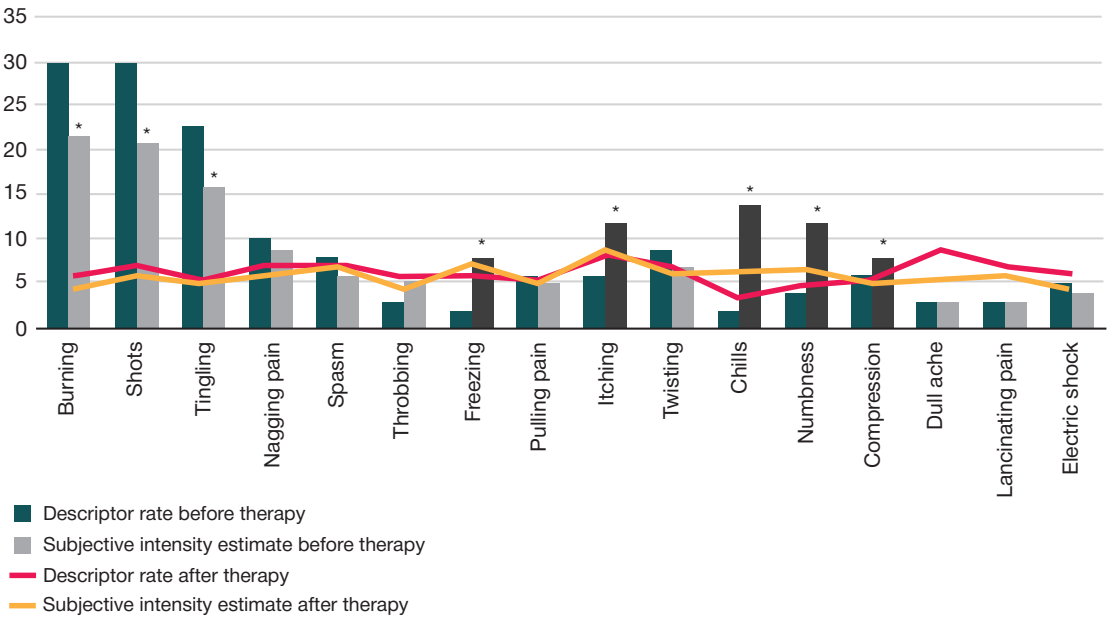

Fig. 7. Relationship between the phantom pain descriptor rates and manifestation intensity in patients before and after the training course involving the use of the FaBo mirror

phantom painful sensations and the VAS pain severity scores. This system of correlations includes the descriptors characterized by maximum rates or maximum intensity. Thus, the total number of descriptors is related to the intensity of burning (r = –0.536) and tingling (r = –0.429) being the most common descriptors; when the intensity is high, the number of descriptors is correlated to the intensity of nagging pain (r = –0.418) and twisting (r = –0.504). The data obtained suggest that the more differentiated is the linguo-semantic designation of the phantom pain manifestation, the lower is the intensity of single manifestations characterizing the phantom pain painful nature.

The second strategy of the linguo-semantic designation of phantom painful sensations in patients with trauma-related amputation of lower limbs is manifested by low differentiation of the descriptors with their high intensity (both aggregate intensity and intensity of distinct descriptors). This strategy is confirmed by the identified direct significant correlations between the total number of descriptors and the intensity of low-rate linguo-semantic descriptors: chills (r = 0.522), numbness (r = 0.427), freezing (r = 0.416), pulling (r = 0.402) and clenching (r = 0.411) pain; as well as between subjective estimates of the intensity of distinct descriptors and the VAS pain severity scores. Thus, it is clear that the more differentiated descriptors are used by the patient to designate the phantom pain manifestations, the higher the intensity of non-painful sensations represented by war veterans with amputation of lower limbs in the linguo-semantic constructs describing the phantom pain manifestations.

The second phase of the study involved 36 individuals admitted to remedial classes involving the use of mirror visual feedback out of 40 patients with trauma-related amputation of lower limbs; they completed the full course, consisting of five training sessions. Re-evaluation was conducted after completing the training course.

Assessment of the significance of differences in the number of descriptors and intensity of their manifestations revealed significant differences in both rates of descriptors and subjective estimates of their intensity. This shows that the rate of such descriptors, as “burning” (p = 0.021), “shots” (p = 0.018), and “tingling” (p = 0.018), which prevailed before the remedial training course, significantly decreased after completing the course of five training sessions. However, these descriptors remained predominant. We should also note a significant increase in the rates of the linguo-semantic meaning the non-painful sensations: “freezing” (p = 0.024), “itching” (p = 0.031), “chills” (p = 0.019), “numbness” (p = 0.021), and “compression” (p = 0.022) (Fig. 7).

Assessment of the dynamic changes in the relationship of the linguistic forms used to designate the descriptors of painful sensations and their semantic contents after the end of the remedial training course involving the use of mirror visual feedback also revealed significant differences. The percentage of verbal nouns decreased significantly (from 44 to 35%), which suggests a shift towards predominance of concrete and material nouns. The percentage of the descriptors characterizing painful sensations also decreased with increasing percentage of the descriptors describing unpleasant (non-painful) sensations (from 75 to 68%). According to reliable indicators, the system of correlations between the number of descriptors of painful sensations in patients with trauma-related amputation of lower limbs having phantom pain and the intensity of painful sensations remained unchanged after the remedial training course (the changes affected the values of significant correlation coefficients only).

Thus, the research results obtained showed that mostly verbal nouns characterizing the painful sensations’ duration (meaning an action, process, or result of an action) are used as linguo-semantic descriptors of phantom painful sensations in patients with trauma-related amputation of lower limbs showing manifestations of phantom pain syndrome with the pronounced intensity that describe various painful sensations.

It should be noted that four patients with trauma-related amputation of the lower limb showing manifestations of phantom pain out of 40 refused further procedures, reporting increased phantom painful sensations, after one or two training sessions. Patients complained that during and after the procedures, the intensity of phantom painful sensations increased, arising against the background of involuntary phantom movements of the amputated part of the limb, which imitated the exercises and movements performed during the procedure: “I feel the amputated part more clearly, how it bends and flexes, aches and hurts”.

DISCUSSION

The image of pain is a holistic linguo-semantic structure, the result of integration of various sensory modalities of

painful sensations. The image of phantom painful sensations presented in the authors' interpretation is most close to the linguo-semantic metaphorical constructs — figurative expressions that contain causal and affective interpretations. Such constructs often reflect not only the intensity of phantom painful sensations, but also the patient's attitude towards this [35]. The differentiated nature of the verbal description of phantom painful sensations in patients with trauma-related amputation of the limbs involving the use of linguo-semantic descriptors is in line with the results of the studies focused on neurophysiological correlates involving the use of mirror visual feedback, i.e. bilateral activation of primary sensorymotor areas of the cerebral cortex [33], which, in turn, corresponds to the cortical level of perceptual organization of the mechanisms underlying the emergence of phantom painful sensations. Subjective assessment of the phantom painful sensation localization mainly in distal parts of the amputated limb can be considered as the indirect evidence of the peripheral level of perceptual organization of the mechanisms underlying the emergence of phantom painful sensations [4].

The image of phantom painful sensations is represented by variability of linguo-semantic descriptors and the image description reflects the contents of the unique experience of reliving and interpretation of various phantom painful sensations. Integration of various sensation types in the verbal description of the image of pain (tactile, muscular, stereognostic) suggests the involvement of the associative cortex of posterior brain regions ensuring synthesis and processing of multimodal information, along with the primary motor and somatosensory cortex.

CONCLUSIONS

The linguo-semantic representation of the image of phantom painful sensations with involuntary movement of various parts of the amputated limb and disruption of the integrity of these parts is characterized by qualitative differences from the phantom pain representation described in terms of exposure to the external stimulus. The other two groups of the linguo-semantic representation of the holistic image of pain (in terms of the external influence or changes in the size and integrity of the amputated limbs) reflect the verbalized process of experiencing the maladaptive cortical rearrangement in the primary motor and somatosensory cortex, rearrangement of sensory maps, while the latter group at the level of the linguo-semantic characteristics represents the holistic image of phantom painful sensations in terms of the subjective sensory-perceptive experience allowing one to explain the origin of such sensations "as if I were holding my hands over a fire," "as if I were standing with my foot in water"). The identified dynamic changes of the linguo-semantic descriptors of phantom painful sensations in patients with trauma-related amputation of the limbs showing manifestations of phantom pain syndrome during therapy involving the use of mirror visual feedback allows one to consider the following as the effectiveness criteria: the increase in the number of descriptors of painful sensations represented mainly in the form of concrete and material nouns (allowing one to reduce the intensity of phantom painful sensation assessed on the 10-point scale), as well as the increase in the number of descriptors characterizing non-painful unpleasant sensations at the linguo-semantic level.

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