Design of rehabilitative and developmental board games for people with impaired motor and cognitive functions

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Abstract. The article presents the results of the development of rehabilitative and developmental board games of varying complexity for people of all age groups with a violation of the musculoskeletal system and cognitive functions by the author team of the Orenburg State University design department. Games are designed to restore and develop motor skills, visual perception, cognitive abilities, logical and spatial thinking. Particular attention is paid to the variability of games and parameters of game chips configuration, with the aim of gradual and continuous improvement of patients’ skills in the rehabilitation process.

1. Introduction
In modern society, there is an increasing social need for the development of rehabilitative and developmental games for people with musculoskeletal disorders that restore both motility and brain activity; intended for all age groups; available for use both in medical institutions and at home.

Throughout the world, the socialization of society part that, due to physiological, psychological and cognitive characteristics, experiences certain difficulties in realizing its labor capabilities, in organizing its life, and in interacting with society, remains relevant. Many of them cannot overcome these barriers due to impaired function of the musculoskeletal system or cognitive impairment acquired in connection with the disease or injuries. Only in our country at present, 12.1 million is granted the status of a disabled person. Many of them have a diagnosis associated with disabilities of different severity.

For example, 70-80% of survivors of a stroke remain disabled and only 20-30% of them irrevocably lose their ability to independently perform elementary functions. Currently, the age of stroke is getting younger and becoming one of the main socioeconomic problems.

The most common violations that limit the ability to perform certain vital functions, communication – impaired memory, speech, motor abilities. The first stage of lost abilities restoration occurs under the direct supervision of medical personnel. However, the recovery process can last more than one year and in the periods between medical recovery procedures, the patient is forced to overcome difficulties at home independently or with the help of loved ones.

The market of medical rehabilitative and development equipment is rapidly developing in the direction of robotization, computerization, and others progressive, but expensive technologies, designed for specialized medical or rehabilitation centers. Domestic and foreign manufacturers are developing personal equipment to continue rehabilitation exercises on their own. Basically, it is also based on computer technology aimed at restoring and developing one or more lost functions in the post-stroke or post-traumatic period and also belongs to the price category above the average.
Almost all categories of patients need special organization of rehabilitation conditions in the home environment. This environment and its content should be accessible to all segments of the population, both wealthy and low-income. In addition, there are practically no proposals for introducing into the home life the simplest to learn and inexpensive, but methodically developed rehabilitation and development technologies that provide a comprehensive restoration of various human functions. For example, the simultaneous restoration of motor functions, memory, etc.

To solve the problem of organizing a patient’s continuous rehabilitation and development process, an integrated approach is needed, combining rehabilitologists, occupational therapists, speech therapists, psychologists, teachers, design engineers and other specialized specialists. Designers are also actively involved in scientific and practical developments. The game techniques used by them in the development of rehabilitation and training kits, first of all, remove the psychological barrier of inferiority in patients and motivate for further rehabilitation actions. The influence of gaming technologies on the effectiveness of rehabilitation and developmental procedures has been confirmed by many world studies and does not require confirmation [1].

Integrated development of rehabilitative and developmental board games for people with impaired musculoskeletal and cognitive functions, performed by the author team of the Orenburg State University design department (Chepurova O.B. – head of the design department, PhD in Art criticism, associate professor; Putintseva T.A. – PhD in Art criticism, associate professor; Shleiuk S.G. – PhD in Art criticism, associate professor; Tuysina D.M. – PhD in Art criticism, associate professor; Tarasova O.P. – PhD in Pedagogic Sciences, associate professor; Chepurov I.V. – senior teacher, Ryabov S.V. – assistant, with the participation of design department students), contribute to the successful solution of this problem.

2. Materials and methods

Rehabilitative and developmental board games are designed to restore and develop motor skills, visual perception, cognitive abilities, logical and spatial thinking of people with impaired musculoskeletal and cognitive functions for all age groups.

Their use is envisaged in various fields: at home, in specialized institutions, including children’s (medical institutions, rehabilitation centers, schools, kindergartens).

It is known that gaming technologies are effective as a method of rehabilitation and training. Thesis research on the subject of games and gaming technologies was carried out by Associate Professor of the OSU Design Department Tuysina (Popova) D.M. [2]. The use of gaming technology in the design of design objects provides a high degree of focus on cognitive activity, includes logic, motility, memory, attention, emotional experiences; have a positive effect on the adaptation of a person in everyday life.

However, it is worth noting that gaming technology is actively used for rehabilitation and set various tasks. During the game, a person not only shows his interest in interaction with game elements, but also fixes the cognitive process in a light form of perception. Therefore, many gaming technology focused on rehabilitation, use this effect for the task. The game as a process of patient interaction with game elements allows not only to maintain concentration, but also to fix the acquired skills. During the design, scenario modeling of interaction with game elements was presented: the game process was studied from the point of view of the logical task in the game and the tasks set, ergonomic parameters of all elements and clear graphic design. The task of restraining the interest in game technologies in patients contributed to the decision to introduce a system of replaceable game elements to expand the game variability. Thus, the emotional state and behavior of the patient in the gameplay were predicted [3]. It was the variation that allowed us to include the phasing of the game process during rehabilitation from simple to complex, depending on the function and task of the game.

When creating rehabilitation and restorative means, a number of methods were used that made it possible to facilitate the interaction of the user contingent with the game elements, taking into account the adaptive capabilities of the person and the disease severity. Among them, the anatomical and anthropometric methods, the scenario modeling method, the percentile method, the method of
compiling a checklist of requirements for the design object are significant. So, data on the structure of the human body and its functional capabilities were required when calculating the parameters of the chip and the playing field (overall dimensions, dimensions of reach of the hands while sitting or standing, muscle strength), taking into account the specifics of the game activity and the health status of the player. In this regard, we studied static, dynamic, and functional features that allowed us to determine the design parameters and scale relationships of the parts and the whole game:

- the height of the working surface (playing field), taking into account the height of the elbow point of the seated player;
- the size and layout of the game elements on the playing field, taking into account the reach of the patient’s hands from different positions and poses that he may occupy due to illness, as well as the nature of the movements that need to be performed during the course of the game;
- weight and size of the chip, taking into account the hand size, patient’s muscle strength and the hands joints mobility;
- determination of the optimal size of the workspace, etc.

In addition, We took into account the specific features of human interaction with the game elements: the need for visual control over the action execution, the need to perform a number of operations with the right or left hand, etc. This approach to the design of game elements allows to optimize the game process due to the ability of the user to take a relatively comfortable pose, because of which his movements will not cause difficulties, as well as increase the duration of the game process, which will contribute to the desired therapeutic effect.

Particular attention in the process of project activities was given to the search for chip parameters. According to the game scenario, when it moves across the field, the player uses the end grip. This method is not always applicable (for example, it cannot be used by patients with some visual agnosia, since with this grip the image located on the upper part of the chip is closed), but it is most optimal with the given restrictions (board game). The design parameters of the chip were selected empirically taking into account the wrist size, the characteristics of the product retention and the patient's ability to control the process of transferring the product along the playing field. At this design stage, the scenario modeling method and the percentile method were used. It was important to identify product parameters that are equally convenient for both men and women, since the contingent of users consists of people with significantly different anthropometric signs of the wrist (transgression within 50-60%) [4] and age characteristics. It is known that with the indicated diseases in age-related patients, the adaptive capabilities of the body are significantly reduced – with age, mobility in the joints decreases, coordination of movements is lost, muscle strength decreases. Therefore, the task of the designers was to determine the weight of the chip and its size, based on optimal efforts and energy costs of all categories of users.

In the course of scenography, a general idea about the proportions and sizes of the projected element was formed, an object structure was formed, based on the principle of a tumbler, a color solution, materials were selected that provided the required shape and function. When using the checklist compilation method, the requirements were formulated for the game elements - its quality characteristics, parameters, graphic solution, functions, etc. User satisfaction with the chip, in particular, suggested that it corresponded to the anthropometric characteristics and wrist functionality, finger mobility, using a positive color scheme and patient-friendly graphics. However, the big difference between anthropometric parameters of the game users that determine the boundaries of its capabilities, as well as their features, required, for example, to unify the object and add allowances for adaptive movements to players with very different body sizes. In turn, the comparative method for compliance and the analysis method were used to search for the degree of stylization of images at the stage of creating thumbnails of graphic game elements, taking into account the presence of a player with a post-stroke state of visual agnosia.

The application of eco-design methods and 3D printer technology made it possible to produce test samples of the game kit basic elements from environmentally friendly material. Polylactide, which includes waste from corn and sugar cane, was selected as the raw material for the manufacture. This is
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a relatively soft plastic that is used in industry for packaging food products, medicine containers, and surgical sutures. Due to the natural composition of the material components, the disposal of products in natural conditions is possible.

3. Results and Discussion

The rehabilitative and developmental games presented in the article relate to indoor games on the boards with small moving playing objects. Many previous developments have been made in this direction.

One of the constructive analogues is the toy "Vanka-vstanka" containing a body with a hollow spherical base and a weight made in the form of a permanent magnet mounted in the body with the ability to move. The magnet is suspended by means of a flexible thread, it has a magnetic interaction with the ferromagnetic material placed in the closed cavity of the base (SU 1519728 A1, 11/7/1989, Bull. No. 41). The disadvantages of this device can be noted its instability and a long period of swinging.

Also known is a magnetic chess device containing a magnetized chessboard, a set of flat metal figures, a leading playing chip with a built-in magnet (RU 2092210, 10.10.1997). But this device does not have playing elements with the necessary anthropometric parameters for people with a violation of the musculoskeletal system and cognitive functions.

One of the modern designs offered in the market of rehabilitative and developmental games is the RehabMedical sound panel "Palletto", which has a high-quality design of the external shape and color. It uses the Braille technique for the development of associative thinking, sounds are recorded and reproduced with a certain set of pictures. However, the high cost of this device allows its use only for a wealthy category of people.

Since 2003, teachers and students of the OSU Design Department have been working on the research and design of rehabilitative and training sets of games for children with musculoskeletal disorders in collaboration with the All-Russian Research Institute of Technical Aesthetics as part of the Design and Life Quality of the Population program. The exhibition "Art Furniture 2004" exhibited and certified the result of joint work on the design of specialized gaming complexes.

In 2008, in the book of PhD in Art criticism, Professor Grashin Alexander Alexandrovich, Head of the Department of Theory and Methodology of Industrial Design and Ergonomics of the Research Institute of Technical Aesthetics of MIREA "Design of a Children's Developing Subject Medium", the results of a design solution for rehabilitation and developing subject-spatial environment, as a base matrix for additions to any rehabilitation and recovery complex in the system of material and educational development facilities for patients with musculoskeletal disorders [5].

The first project proposals of the design department presented in this book demonstrate rehabilitative and developmental games, in their anthropometric parameters, designed only for children. They include playing chips that do not contain replaceable cards, which deprives the game system of variability; the base of the playing chips is made in the form of a hemisphere, which leads to instability and prolonged swaying of the playing chip during the game; the side surfaces of the playing chips are even and smooth, which makes it difficult to fix them in the player's hand. Testing of the developed products made it possible to identify a number of significant shortcomings and continue further research, taking into account their formative qualities, methodological content, technological design and the expansion of functional use for all age categories.

Thus, the main tasks for us in developing rehabilitative and developing board games for people with impaired musculoskeletal and cognitive functions were:
- giving a set of properties to the playing chips which are necessary for people with musculoskeletal disorders of all age groups: the necessary anthropometric parameters, improving the quality of fixing the playing chip in the player's hand, increasing the stability of the playing chip in combination with the ability to take a vertical position from an inclined position;
- increasing the degree of variability of the game.
The rehabilitative and development board games developed by us for people with disorders of the musculoskeletal system are equipped with a game field, game chips, exchangeable cards for the playing field and exchangeable cards for game chips, packaging. An example of the game is shown in Figure 1. Consider its structure and principle of operation.

The game chip consists of a base and a top with a lid, as can be seen in Figures 2 and 3. These elements are fastened to each other by inserting on the elastic properties of the material. As mentioned above, the game chip is made of lightweight impact-resistant eco-friendly plastic using 3D printing technology.

The base of the game chip has a hollow hemisphere design in which a metal load and filling material are located.

The top consists of a cylindrical part with a cover.

The cylindrical part of the pommel is made in the form of a sleeve with a ribbed side surface, for maximum ease of holding it in the hand of a participant in the game. On the lid of the pommel there is a magnetic layer for holding exchangeable cards of game chips.

Dimensional and structural characteristics of the game chip correspond to the anthropometric parameters of the hands of the players, anatomical plastic; power, speed, biomechanical and other capabilities of the players.

![Figure 1](image.jpg)

**Figure 1.** An example of solving rehabilitation and developing board games for people with impaired musculoskeletal and cognitive functions. The graphic part was performed by Victoria Trubitsyna, a student (D. Tuysina, teacher).

The playing field has several layers: a magnetic layer is placed on the basis of the playing field (for holding game chips of exchangeable playing field cards by the attraction method). Above is the layer of the graphic solution for the playing field. The game field contains sections for the location of removable cards.

Replaceable playing field cards and replaceable playing chip cards have a magnetic layer for attracting, respectively, to the field and to the chips. The media layer with a graphic image is the top layer of removable cards.

Graphic images located on removable cards correspond to the scenario and semantic concept of the current game and may change with the start of a new game.

All game elements are compactly placed in a package.

Using the principle of shifted center of gravity in the organization of the shape of game chips ensures their stability. To do this, in a specially prepared cavity at the base of the game chip is placed a
metal load with a large mass. This is the main innovative constructive and functional solution to the game.

The functional value of this principle lies in the comfort of the game process: a game chip, at any deviation from the vertical, restores its original position on the playing field.

The stability of the game chips is enhanced by the magnetic attraction of the metal load to the magnetic layer of the playing field.

The logical concept of games is as follows. During the game, the participant performs exercises to restore and develop hand motor skills (interaction with game chips), as well as to restore and develop memory and logic (remembering and repeating basic visual images and logical sequence of actions).

Games are aimed at expanding the zone of immediate opportunity. Due to the varying complexity of the games, it is possible for people of the combined contingent of different age groups to participate; simultaneous participation of one, two or more people, participation of an assistant.

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**Figure 2.** Game chip; game chip with a removable card placed on it. Chips were developed and designed by: Chepurova O.B., Putintseva T.A., student Nikitenko T., Ryabov S.V.

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**Figure 3.** The base of the game chip; the cylindrical part of the game chip top; game chip cover.

The principle of the game: in the sectors of the playing field are replaceable cards of the playing field of the chosen topic (by magnetic attraction), on the playing chips are replaced by cards of playing chips of the corresponding theme (by magnetic attraction), the player takes the playing chips by hand and puts them on the replaceable cards of the playing fields corresponding in meaning.

The semantic concept of games for compliance consists in the associative recall by the game participants (using semantic associative pairs) of the correspondences, situations, phenomena, images that are most often encountered in life and necessary for a full perception of the world. It is always necessary to restore the logical connections of everyday objects in everyday human activities. It can also be interesting and informative for the patient to develop and restore knowledge about natural laws, etc. In this case, the participant puts a game chip with a replaceable card on the playing field on the corresponding pair of replaceable cards.

A more complex level of games is the work with letters and words. Letters are placed on replaceable cards of game chips; words are composed of letters.
The options for the semantic concept of games are infinitely diverse - tic-tac-toe, checkers, chess and many other favorite games.

Thus, games possess high variability, visibility for players. The graphics of game chips and sectors of the game field can be changed depending on the level of complexity and plot of the game, replacing replaceable cards of game chips and replaceable cards of the game field. Thus, if necessary, you can easily change the theme of the game to another.

Graphic design is an important factor in the degree of complexity of the gameplay. In the course of work on illustrative material using the method of comparative analysis, graphics sketches of game elements were developed. It is worth noting that the graphic component of the game allows to include different degrees of difficulty in perception, thereby being variative and multi-level. At the same time, interchangeable graphics for the playing field and chips allow setting certain development goals. The chosen technique of illustrative material execution allows to quickly and clearly read the silhouettes of objects depicted on the chips and the playing field. The silhouettes are pastiche; proportional relationships between themselves in the images are preserved. Each game contains its own script depending on the tasks and topics of the illustrative material.

Figure 4 presents one of the concepts of graphic design, which already has the second level of visual perception complexity, in contrast to simple geometric shapes. It is intended to study the color ratios of images on chips to achromatic images on the playing field. The color layout was selected taking into account visual perception and tonal correlation of shades among themselves [6]. For greater contrast, the background on the playing field and chips remains white. Each color and tone in a person is associated with emotions and feelings. Thanks to the correct layout of the color the attention and memory of the patient can be improved. For reliability, the color gamut of each image was selected from the original image, so as not to mislead the person. Isolation of the desired silhouette from similar color and tonal ratios increases the degree of complexity. The silhouette outline of each image is crisp and original.

![Figure 4](image-url)

**Figure 4.** An example of the graphical solution concept to rehabilitative and developmental board games for people with musculoskeletal disorders. The graphic part was carried out by student Drozdova Tatyana (Tuysina D.M., teacher).
The second version of the game process includes searching not color dice, but a silhouette solution of images and their contour execution. This solution has a more complex degree of visual perception. Monochrome design makes it easier to find the silhouette of the necessary chips with the image on the playing field. Graphic stylization of a three-dimensional object in a flat form simplifies the perception of the patient and increases the speed of visual recognition of the image. Such a solution maintains the patient's interest in game elements as a solution to the problem and encourages further gameplay. The presented concept of the graphic design of the game is designed for corrective action on the visual apparatus of the patient. And game therapy tasks are aimed at accumulating visual information from the player.

The requirements for the designed objects are objectively reflected in the formulation of criteria and indicators for assessing their quality. Criteria, as signs, on the basis of which the design object is evaluated, contribute to obtaining the most complete picture of its quality condition during operation. The indicators, in turn, describe the characteristics and features of the created product. When evaluating the criteria and indicators of the rehabilitation and developmental game, the following list of criteria and indicators was used:

- aesthetic, which determines the external attractiveness and artistic expressiveness of the game, due to which there is interest and sympathy for the object of the user. This fact is very important, as in many patients the existing way of life is destroyed as a result of the disease, which often causes psychological trauma and refusal of rehabilitation therapy;
- ergonomic criterion assumes that the design object matches the anthropometric, psychological, psychophysiological and other features of the target audience, taking into account the specifics of the gaming activity tasks in order to restore lost functions and the conditions for rehabilitation and developmental games in a medical institution or in everyday life;
- functional criterion assumes that the product meets its intended purpose in terms of design, levels and variety of practical applications, the intended rehabilitation and restoration effect;
- environmental criterion is designed to assess the degree of psychological and physical safety in the use and safety of the product;
- operational criterion requires ensuring easy maintenance and storage of product elements, strength, wear and shape stability of the product, allowing its active use to maintain consumer qualities and attractive appearance;
- economic criterion suggests the possibility of acquiring a set of games for self-sustaining continuation of rehabilitation therapy to a large group of patients with impaired functions.

4. Conclusion

The presented rehabilitative and developmental board games for people with disorders of the musculoskeletal system and cognitive functions contribute to the successful solution of the problem of restoring lost skills and adapting them in everyday life.

Unlike well-known technical solutions, these games contain a playing field with a magnetic layer, replaceable cards of the playing field with a magnetic layer, replaceable cards of playing chips with a magnetic layer; playing chips have anthropometric characteristics for people with disorders of the musculoskeletal system of all age groups, a ribbed (textured) side surface to improve the quality of fixing a playing chip in a player’s hand, a magnetic layer for fixing replaceable playing card cards, a metal weight in the base for the ability of a chip to accept vertical position from inclined; the base of the chip has a complex shape - the surface contour of the base of the playing chip is presented in the form of conjugations of circles.

In developing the design of the games, ergonomic criteria came in first place - the ability to easily capture and hold the game chip, the correspondence of its shape to the anthropometric parameters of the players' hands, anatomical plastic; compliance with power, speed, biomechanical, etc. As a result, the design of the chip provides ease of capture by the player, a quick return from any position to the original vertical.
All elements of the games are made from environmentally friendly materials, safe and harmless to use, simple and convenient during the game. Original authoring graphics and a thematic approach to creating games form vivid imaginative solutions of a positive orientation.

The author team of the design department obtained a patent for the invention of a rehabilitative and developmental board game for people with disabilities, designed to restore hand motor skills, visual memory, cognitive abilities and logical thinking of people with impaired musculoskeletal and cognitive functions of varying complexity [7]. The rehabilitation and developing board games developed by us are an element in the rehabilitation and restoration of the subject-spatial environment.

Further development of design in this direction involves the sets of games development with high variability of configuration and parameters of game chips, variability of the graphic solution in order to diversify rehabilitation and recovery games. This will make it possible to gradually and continuously improve the skills of patients of all age groups of any severity of the disease in the process of rehabilitation.

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According to the conclusions of rehabilitologists, the result of testing made it possible to recognize the set of games with methodological material of varying complexity as effective, which allows combining recovery procedures for speech, cognitive and motor functions in a single process. Game technologies have become a motivator for patients to continue to interact independently with the kit both in specialized institutions and at home, which has helped to organize a continuous rehabilitation process and improve recovery processes.

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