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*Research article*

# The effects of 6-weeks program of physical therapeutic exergames on cognitive flexibility focused by reaction times in relation to manual and podal motor abilities

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**Abstract:** The main purpose of the study was to identify the level of improvement in cognitive flexi-bility manifested by choice and cognition reaction times in relation to manual and podal skills as a result of the implementation of a program of therapeutic exergame exercises, for a time interval of 6 weeks at the level of students. 511 students participated in the cross-sectional study, of which 279 male (54.6%) and 232 female (45.4%), divided into two groups: the experimental group 266 (521%) subjects and the control group 245 (48%) sub-jects. The implementation of the experimental program comprising of 8 physical thera-peutic exergames took place for 6 weeks, in one session per week, within the physical edu-cation lessons, only for the male and female experimental groups. In the initial and final testing session, 2 standardized tests were applied: TMT part A, B and 2 tests adapted for this study: Square Test and 25 Squares Test. The progress registered by the male and fe-male experimental groups was statistically significant. In all tests, the experimental groups showed higher progress compared to the control groups. Depending on the gender differences, it was found that the male experimental and control groups made better pro-gress compared to the female groups in the following tests: TMT part A, Square Test, 25 Squares Tests. The implementation of a physical therapeutic exergame program deter-mined the improvement of cognitive flexibility man-ifested by choice and cognitive reac-tion times in conditions of manual and podal motor skills, demonstrating the effective-ness of exergame technologies adapted and implemented for prophy-lactic purposes.

**Keywords:** physical therapy; kinetoprophylaxy, recovery; students; choice reaction time; cognitive reaction time; motor ability; adapted exergame; cognitive ability.

## 1. Introduction

Prophylactic cognitive and motor physiotherapy contributes to maintaining and improving health, cognitive functions and fitness through specific means, and exergames adapted to physiotherapeutic and prophylactic requirements and principles and to individual characteristics can be viable and effective means in optimizing health and human functional and motor potential. The interrelationship between cognitive and motor capacities, delimited by the concept of psychomotricity, influences the way the organism performs [1,2]. Physical exercise performed for prophylactic or therapeutic purposes can contribute to the optimization of health and to the efficiency of the preventive and recovery process of human motor and cognitive functions [3,4]. Preventing the decline of cognitive and motor functions is a major objective of health education that is conditioned by the duration of this process and by the conditioning factors. Studies have shown that physical exercise has undeniable beneficial effects in the optimization of psychomotor functions through which the connection between the mental and the motor plane is realized, mainly manifested by the reaction time to different stimuli [5-8]. The cognitive performance influences the quality of manifestation of the motor capacity with a predominant focus on the components of: reaction time, motor agility and coordination. The cognitive flexibility as a higher executive function aims at the ability to control, change and associate different elements in response to the demands of the task consisting of conscious mental operations [9,10].

The reaction time is influenced by the level of development of the muscular sense, the plasticity of the nervous processes, the complexity and difficulty of the motor task, cognitive flexibility, motor experience, precision and speed of execution [2,11,12]. Depending on the stimulus, the reaction time can be: simple, choice and cognitive [10-14]. Choice reaction time involves the duration between the presentation of stimuli arranged in a certain order or random and the activity of selecting and ordering them according to the task received based on predetermined criteria [14,15]. Cognitive reaction time is influenced by the complexity of cognitive processes and the characteristics and nature of the stimulus and includes the following operations: decoding, analysis, association and application of information [16,17]. In physical therapy, as well as in physical activity, an adequate reaction time is an indicator of health status, respectively of optimal cognitive and motor functioning [4,17].

Studies have shown that the manifestation level of reaction time to simple and complex stimuli is influenced by cognitive functions [18-20]. The reaction time is composed of a cognitive and a motor component, the cognitive or "premotor" component can have a significant contribution correlated with the stimulus characteristics [21,22]. Cognitive reaction time involves a mental process of selecting the optimal response to multiple and/or differentiated stimuli, and the response is dependent on the typology, characteristics and shape of the stimuli [23,24]. The perception, processing and response to stimuli is usually manifested in milliseconds, the choice and cognitive reaction time is dependent on: perceptual acuity, the type of stimulated perception (auditory signals are processed faster than visual ones), the age of the subjects, the ability to pay attention the quality of the processing capacity of the SNC and the motor response speed [25,26].

Exergames are modern and interactive technologies that combine exercise with video games to improve health and fitness [27,28]. Increasingly extensive applicability and in a continuous dynamic of these technologies in prophylaxis and physiotherapy focused on the analysis of reaction times in relation to the movements of the segments or body in order to achieve a progress specific to the type of exergame [29,30]. Physical therapeutic exergames are technologies created and adapted to the specific therapeutic requirements of the preventive and cognitive, neuromotor and motor rehabilitation process [31,32]. Some studies have investigated how different virtual and informational technologies influence the reaction time [33,34]. The studies that aim at the effects of exergames adapted for physiotherapy and prophylaxis are relatively few, and most of them aim at the aspects of motor recovery and functional rehabilitation after a wide variety of ailments or medical problems [35,36]. Relatively few studies focus on improving cognitive flexibility with a focus on choice and cognitive reaction times for prophylactic purposes [37,38]. The novel aspects of this study consist in the selection, adaptation and implementation of a program of physical therapeutic exergames in order to improve choice and cognitive reaction times in relation to manual and podal motor skills. Also, the reaction time evaluation tests were adapted to involve manual and podal motor skills of the subjects included in the study.

The main purpose of the study was to identify the level of improvement in cognitive flexibility manifested by choice and cognition reaction times in relation to manual and podal motor skills as a result of the implementation of a program of therapeutic exergame exercises, for the duration of 6 weeks at the level of students. The secondary purpose was aimed at identifying the differences in the progress of choice and cognitive reaction times in relation to manual and podal motor skills between the male and female individuals as a result of the implementation of the physical therapeutic exergames program.

## 2. Materials and Methods

### *2.1. Participants.*

511 students participated in the cross-sectional study, of which 279 male (54.6%) and 232 female (45.4%), divided into two groups: the experimental group 266 (521%) sub-jects and the control group 245 (48%) subjects. The experimental group consisted of 147 males (55.3%), 119 females (44.7%), and the control group consisted of (132 males (53.9%), 113 females (46.1%). Average age ± SD of samples: experimental group 21.92 ± 2.58 (male 22.13 ± 3.11, female 21.89 ± 2.17), control group 21.73 ± 2.61 (male 21.79 ± 2.87, female 21.62 ± 2.35). The subjects of the experimental and control groups were students from the first and second year of undergraduate studies who actively participate in physical education classes with a time interval of 2 hours per week. The difference between the two groups regarding physical training consisted in the content of the programs, thus, the experi-mental group performed the physical therapy of exergames program, while the control group practiced a content of aerobic exercises combined with sports games and athletic exercises. The students were selected from the university programs of: general medicine, balneokinetherapy, dentistry, sciences. Inclusion criteria in the study: students in the 1st-2nd year of academic studies, age 19-24 years, good health, full participation in tests, full practice of the physical therapeutic exergames program for the experimental group.

### *2.2. Study Design*

The study took place during the second semester of the 2022-2023 academic year, structured in three stages: initial testing – a single testing session at the beginning of the study (February 2023); implementation of the physical therapeutic exergames program for a duration of 6 weeks (February - April 2023); final testing – a single testing session at the end of the study (April-May 2023). The test sessions were carried out under similar conditions for all participants and included 4 standardized tests adapted to the objectives of the present study. The order of application of the tests was identical for each subject, two attempts were performed and the best result achieved for each test was taken into account.

The experimental program aimed at combining kinetoprophylaxis exercises with those specific to exergames; the exercises were selected so as to contribute to the development of manual and podal skills, general coordination, spatial orientation and motor and cognitive reaction speed. The implementation of the experimental program comprising 8 physical therapeutic exergames was carried out for 6 weeks, only in the male and female experimental groups. The program was identical (from the point of view of the exercises and the duration of the exercise) for all the subjects of the experimental group and was implemented within the physical education lessons, with a duration of 100 minutes / per session / per week. The design of the experimental program and the selection of exergames respected the objectives of the study, the particularities of age, the level of agility development, the development of coordination and spatial orientation.

The following equipment was used for the exergames program: Fitlight® Technology [39,40]; (2 sets x 8 wireless LED spots), exergames through video projection, interactive whiteboard (diagonal: 190 cm, active tactile area, response time ≤ 8ms). The equipment used in the study allows the real-time monitoring of the executions, being designed to improve the components of physical fitness and proprioception, having applicability in: physical therapy, motor and functional rehabilitation and in physical activities [41-43].

All authors of the study contributed equally for this article. All the subjects of the study participated voluntarily based on an informed consent by observing the principles of the Declaration of Helsinki. The study was approved on November 7, 2022, by the Review Board of the Physical Education and Sports Program of G.E. Palade University of Medicine, Pharmacy, Science, and Technology of Targu Mures, Romania.

*2.3. Measures*

In the initial and final testing session, 4 tests were applied to evaluate the level of development of choice and cognitive reaction times in terms of manual and podal motor skills: 2 standardized tests - Trail Making Test (TMT) part A, B and 2 tests adapted for this study – Square Test and 25 Squares Test. The tests were thus selected and designed to involve rapid changes of direction in manual and podal executions in the identification of the stimuli of the 4 tests. The TMT part A, B test involves manual executions (touching the circles on the touch screen of the smart board), the square test involves podal executions (jumping in the squares marked on the ground), and the 25 square test involves combining manual executions with podal ones (jumping in the squares with numbers, the hand touch of the Fitlights that light up).

The TMT part A, B with application for cognitive flexibility assessment is focusing on cognitive reaction time to visual stimuli in combination with manual motor ability. The test is performed on smart boards with a tactical screen, with a diagonal of 190 cm. The TMT test consists in identifying and touching with either hand the circles with included numbers (part A), respectively the circles with included numbers and letters (part B); the circles are randomly arranged on the tactical screen of the smart board. TMT part A, for evaluating choice reaction time of cognitive flexibility, includes 25 numbers included in small circles that must be identified and touched on the screen in ascending order. TMT part B, called cognitive reaction time of cognitive flexibility, consists in identifying and combining in ascending order the 13 circles with numbers from 1-13 with the 12 circles with letters from A-L, thus 1-A...4-D... up to 13. In the case of both parts A and B of the TMT, the best result from two attempts measured in seconds, is counted [44,45].

Square Test evaluates choice reaction time of flexibility cognition in conditions of podal motor ability. A large square with a side of 3 X 3 m is drawn on the ground with colored tape, and inside it, 2 vertical and horizontal lines are drawn so that 9 small squares with a side of 1x1 m each result (Figure 1). Numbers from 1-9 are written inside each square according to Figure.1. The subject is placed in an orthostatic position in the Start square, and at the sound signal, he jumps on both feet in the square according to the numbering, in ascending order from 1 to 9, the completion being when he reaches again in the starting area. The time to complete the entire execution is quantified. It is not allowed to step out of the squares or to perform jumps on only one leg; each error is penalized by 1 sec.

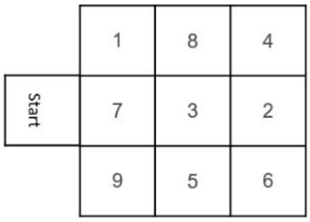


Figure 1. The Square Test - arranging the numbers in the squares

*25 Squares Test* evaluates the cognitive reaction time of flexibility cognition in conditions of combined motor ability: manual and podal. A large square with a side of 5 X 5 m is drawn on the ground with colored tape, and inside it another 4 vertical and horizontal lines are drawn, resulting in 25 small squares with a side of 1x1 m each. According to Figure 2, inside the 24 squares (without the Start square) 12 numbers are written, and in the free squares the 12 Fitlight spots are placed on a tripod with a height of 60 cm. The subject starts the test from the starting area, in orthostatism, at a sound signal he performs jumps on one leg in square number 1, then moves to the square where he touches the first Fitlight spot that illuminates with his hand, then jumps in square number 2 and continues with moving to the next square where he touches the second luminous Fitlight spot with his hand and so on, until the test is completed and he returns to the Start area. The Fitlight spotlights illuminate randomly, being programmed in advance. The test is completed when the subject jumps to square number 12, after which he moves and touches the last Fitlight spot with his hand and returns to the Start area. The best time to complete the entire test from the 2 attempts is quantified in seconds.

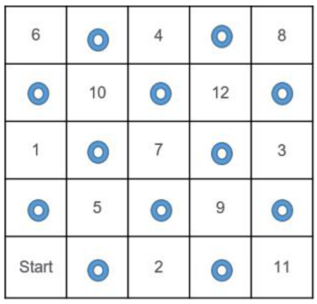


Figure. 2. The 25 Square Test - the arrangement of numbers and Fitlight spots

*2.4. Statistical Analysis*

To process the results, we used the IBM-SPSS 22 software, calculating the following statistical parameters: average (X); standard deviation (SD); the Student's test (t), the con-fidence interval (95% CI); the size effect (d), the progress between tests (ΔXTs). The inter-pretation of the Cohen's d effect size (d): 0.1–0.2 small, 0.3–0.5 medium, 0.5–0.8 large, and over 0.8 very large; level of statistically significant result $p < 0.05$.

## 3. Results

The results of the study were centralized and statistically processed, and the most relevant data were included in Tables 1-4 in order to highlight the statistical relevance, the differences and the size of the effects produced by the independent variable of the study, namely the training program including physical therapeutic exergames.

**Table 1.** Statistical analysis of the results of the TMT part A (manual execution)

| Test | Group | Gender | TiX ± SD | TfX ± SD | ΔXTs | 95% C.I. Lower, Upper | *t* | *p* | d |
|---|---|---|---|---|---|---|---|---|---|
| TMT part A | GE | Male | 41,40±3,65 | 37,48±3,44 | 3,92 | 3,33; 4,50 | 13,176 | ,000 | 1.10 |
| | | Female | 41,45±3,76 | 37,68±3,58 | 3,77 | 3,12; 4,42 | 11,438 | ,000 | 1,02 |
| | GC | Male | 41,74±4,62 | 39,67±3,95 | 2,07 | 1,34; 2,80 | 5,627 | ,000 | 0,48 |
| | | Female | 41,51±3,97 | 39,52±3,88 | 1,99 | 1,21; 2,76 | 5,080 | ,000 | 0.50 |

GE –experiment group, GC- control group, Ti, initial test, TF—final test; X-arithmetic average; SD-standard deviation; *t* - Student's Independent *t*-test; ΔXTs-progress of X(Ti-Tf); CI–interval of confidence; d-size effect, p – statistical significant level.

Analyzing the results (Table 1.), it is obvious that the progress recorded by the female and male experimental groups is superior to the control groups. The arithmetic mean values fell between the two limits of the 95% CI. For all study groups, the differences in the arithmetic means between the initial testing and the final testing were statistically significant for $p<0.05$. The difference in progress between the two female groups was 0.78 seconds in favor of the experimental group; in the male groups, the difference between EG and CG was 0.93 sec. In relation to the gender of the groups, it was found that the male subjects progressed more than the female subjects; thus for the CG the difference between the male and female sample was 0.22 sec; for CG of 0.08 sec. The extent of the size effect was very large, both experimental groups (female and male) being very wide >1, while the control groups recorded values lower than 0.5, which reflects a medium level size effect.

**Table 2.** Statistical analysis of the results of the test TMT part B (manual execution)

| Test | Group | Gender | TiX ± SD | TfX ± SD | ΔXTs | 95% C.I. Lower, Upper | *t* | *p* | d |
|---|---|---|---|---|---|---|---|---|---|
| TMT part B | GE | Male | 71,63±8,90 | 66,47±7,80 | 5,16 | 1,50; 8,80 | 2,782 | ,006 | 0,61 |
| | | Female | 71,86±9,04 | 65,89±6,82 | 5,97 | 1,96; 9,70 | 2,967 | ,003 | 0,74 |
| | GC | Male | 71,64±12,31 | 68,44±11,79 | 3,20 | -,39; 6,78 | 1,754 | ,081 | 0,26 |
| | | Female | 71,91±13,11 | 68,37±11,45 | 3,54 | -,18; 7,54 | 1,875 | ,062 | 0,28 |

GE –experiment group, GC- control group, Ti, initial test, TF—final test; X-arithmetic average; SD-standard deviation; *t* - Student's Independent *t*-test; ΔXTs-progress of X(Ti-Tf); CI–interval of confidence; d-effect size, p – statistical significant level .

The female experimental and control groups made greater progress than those of the male groups. Comparing groups according to the differentiation by gender, we note a difference in progress in favor of the female ones of 0.81 sec. for the experimental samples and 0.34 sec. for the control groups. Analyzing the progress of the male groups, we find a difference of 1.94 seconds in favor of EG, and in the case of the female groups, this difference was 2.43 seconds for the EG. The progress recorded by the two experimental groups was statistically significant and fell within the nine limits of the 95% CI; the progress of the control groups was statistically insignificant, where $p>0.05$. Analyzing the results of Cohen's d for this test, we find that the male experimental groups recorded a wide size effect, the values falling between 0.5 - 0.8, which demonstrates the effectiveness of the physical therapy exergames program; in the case of the control groups, the size effect was small, registering values <0.3 (Table 2).

**Table 3.** Statistical analysis of the results of the Square Test (manual execution)

| Test | Group | Gender | TiX ± SD | TfX ± SD | ΔXTs | 95% C.I. Lower, Upper | *t* | *p* | d |
|---|---|---|---|---|---|---|---|---|---|
| Square Test | GE | Male | 11,87±1,78 | 9,47±2,99 | 2,40 | 1,96; 2,83 | 10,885 | ,000 | 0,97 |
| | | Female | 12,19±1,85 | 10,18±2,75 | 2,01 | 1,57; 2,44 | 9,049 | ,000 | 0,85 |
| | GC | Male | 12,11±3,97 | 10,94±2,71 | 1,17 | ,69; 1,63 | 4,881 | ,000 | 0,34 |
| | | Female | 12,51±3,74 | 11,43±2,65 | 1,08 | ,63; 1,52 | 4,771 | ,000 | 0,33 |

GE –experiment group, GC- control group, Ti, initial test, TF—final test; X-arithmetic average; SD-standard deviation; *t* - Student's Independent *t*-test; ΔXTs-progress of X(Ti-Tf); CI–interval of confidence; d-effect size, p – statistical significant level .

For the Square test, the progresses achieved by the experimental and control groups, male and female, were statistically significant (Table 3). For all groups, the recorded progress fell between the two levels of the 95% CI. The male and female experimental groups recorded a very large size effect, the values being >0.8; for the control groups, the size effect was average, Cohen's values being towards the inner limit of the 0.3-0.5 interval. Comparing the progress between the groups according to gender, we find that the male subjects progressed more than the female ones, by 0.39 sec. in the case of the experimental groups and by 0.11 sec. in the case of control groups. Between the male EG and CG there was a difference in progress of 1.23 sec., and between the female ones of 0.93 sec.

**Table 4.** Statistical analysis of the results of the 25 Squares Test (manual and foot executions)

| | Group | Gender | TiX ± SD | TfX ± SD | ΔXTs | 95% C.I. Lower, Upper | *t* | *p* | d |
|---|---|---|---|---|---|---|---|---|---|
| 25 Squares Test | GE | Male | 46,11±6,01 | 41,71±5,92 | 4,40 | 2,91; 5,89 | 5,817 | ,000 | 0,73 |
| | | Female | 50,01±6,42 | 45,95±5,95 | 4,06 | 2,31; 5,79 | 4,578 | ,000 | 0,65 |
| | GC | Male | 47,56±7,29 | 45,35±7,57 | 2,21 | ,31; 4,10 | 2,292 | ,023 | 0,29 |
| | | Female | 50,71±7,22 | 48,62±7,20 | 2,09 | ,401; 4,18 | 2,388 | ,018 | 0,28 |

GE –experiment group, GC- control group, Ti, initial test, TF—final test; X-arithmetic average; SD-standard deviation; *t* - Student's Independent *t*-test; ΔXTs-progress of X(Ti-Tf); CI–interval of confidence; d-effect size, p – statistical significant level .

The results in Table 4 highlights superior progress of the male experimental group compared to the female one of 0.34 sec. Male control groups progressed by 0.12 sec. more than the female control group. Comparing the experimental male groups with the control ones, we identify a difference in progress of 2.21 sec.; and in the case of female groups of 1.97 sec. The progress values, for all groups, fell between the lower and upper limits of 95% CI. In this test, the progress recorded by all 4 groups was statistically significant p < 0.05. The difference in progress between the two male groups was 2.19 seconds in favor of the experimental group; in the female groups, the difference recorded between EG and CG was 10.77 sec. The magnitude of the size effect was large for both experimental groups (female and male), while the control groups recorded a small size effect, values being <0.3.

## 4. Discussion

The present study mainly aimed at identifying the level of improvement in cognitive flexibility manifested by choice and cognition reaction times in relation to manual and podal motor skills as a result of the implementation of a program of therapeutic exergame exercises, with a duration of 6 weeks at the level of students. As a secondary goal, we focused on identifying the differences in the progress of choice and cognitive reaction times in relation to manual and podal skills between the male and female samples as a result of the implementation of the physical therapeutic exergames program. The results of the experimental groups were superior to the control groups in all tests highlighting the effectiveness of the physical therapeutic exergames program. Comparing the progress recorded by the experimental and control groups according to the gender differences, we can see that the male experimental and control groups have made superior progress compared to the female groups similar to the following tests: TMT part A, Square Test, 25 Squares Tests. Only in TMT part B, female experimental and control groups progressed more than similar male groups. We believe that the complexity of the TMT part B test, which requires a complex cognitive and task-combining capacity, determined these differences.

The results of our study highlight the impact of physical therapeutic exergame implementation in order to improve cognitive flexibility and contribute to the expansion of knowledge regarding the effects of these types of technologies on choice and cognitive reaction times in relation to manual and podal exercises. The results of our study are in line with previous research that highlighted the role of different types of physical and kinetotherapeutic exercises that use information technologies on improving cognitive flexibility [46-48], and implicitly on optimizing motor capacity [49,50]. In our study, the method of application of the four tests was adapted to executions under conditions of manual and podal ability, TMT being performed on touch screens, and the other two tests were adapted to executions in the gym. These adaptations of the application of the tests aimed at the contribution of specific manual and podal executions embodied in jumps, changes of ocular-manual coordination of direction in relation to the tasks of the stimulus or the test. A series of studies highlighted positive correlations between the level of cognitive flexibility and the level of human motor skills [51-53].

In our study, the superior progress obtained by the male groups compared to the female groups in most tests, we consider to be the result of the influence of the higher level of manifestation of the manual and especially the podal motor skills, a fact highlighted in previous studies [54,55]. Physical therapeutic exergames, through their variety and applicability, contribute to the improvement of specific physical fitness parameters [56-58], and some cognitive parameters [59,60]. A series of studies have highlighted that the selection and implementation of physical therapeutic exergame can have major influences in the motor rehabilitation process or in kinetoprophylaxis if the age, health, functional and motor characteristics of the subjects are respected [61-63].

Numerous studies have approached the evaluation of the way in which physical therapeutic exergame contributes to the improvement of health and functional capacity [64,65], as well as to the rehabilitation of: neuromotor, motor and cognitive functions [66,67]. A series of studies have been approached in correlation with our topic, they have targeted different categories of subjects from children to the elderly, concluding that exergames can have a major influence in the therapeutic and prophylactic activity for different medical problems in different age groups [68,69]. Specialized technologies and prophylaxis programs in order to improve cognitive flexibility and motor skills must be approached interdisciplinary in order to highlight the effectiveness and complexity of the effects and the efficiency of the methods of application and practice in specialized conditions.

The limits of the research: the relatively short duration of only 6 weeks for the implementation of the physical therapeutic exergames program due to the fact that the academic training module has 7 weeks, the limitation of the selection of subjects only to the age range of 19-24 years. The strengths of the study: the selection and adaptation of physical therapeutic exergames to be performed on touch screens, the application and adaptation of the 4 standardized tests according to the objectives of the study, the relatively large number of subjects included in the study, the comparative analysis of the female and male groups.

## 5. Conclusions

The implementation of a physical therapeutic exergame program determined the improvement of cognitive flexibility manifested by choice and cognitive reaction times in terms of manual and podal motor skills. The results of the experimental groups were superior to the control groups; the level of choice and cognitive reaction time was higher at the level of the male samples compared to the female ones for: TMT part A, Square Test, 25 Squares test. The only exception was registered at TMT part B, where the female samples recorded superior progress compared to the male ones. Physical therapeutic exergames can have varied applicability in physical therapy, in kinetoprophylaxis with a focus on optimizing motor and cognitive capacity. Future research will have to be focused on highlighting the effectiveness of different physical therapeutic exergame programs in the process of motor and functional rehabilitation for different categories of subjects, as well as in the process of optimizing physical fitness and health.

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