

Exercise for Cognitive Improvement and Rehabilitation (EXCIR) Improves Attention and Executive Functions in Children with ADHD

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Research

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Abstract

Background: Physical activities improves cognitive functioning. The purpose of the present study is to effect of physical activity with progressive cognitive demands on attention and executive functions in children with ADHD.

Methods: Thirty children with ADHD were randomly assigned into two equal experimental and control groups. The experimental group received 12 sessions of exercise for cognitive improvement and rehabilitation (EXCIR). Working memory, selective attention, sustained attention, inhibitory control and cognitive flexibility were administered pre- and post-intervention through 1-back test, Stroop test, attention registration test, go no go test and trial making test in order. The repeated measure ANOVAs were used for analysis.

Results: The results showed that experimental group has a greater performance in selective attention, sustained attention, inhibitory control and cognitive flexibility compared to control group.

Conclusions: These findings implicate that the cognitive rehabilitation program is advantageous for improvement of attention and executive functions in children with ADHD.

Background

Our life style could shape our brain. Numerous studies found the effectiveness of different domains of life style on cognitive functioning including nutrition [1], enriched environments [2], sensory information [3], physical context [4], and physical activity [5].

Given the mutually interaction between the brain and behavior [6], as the brain injuries could obviously affect our behaviors, behavioral training can also modify the neural underpinning of behavior. Thus, all behavioral changes (in terms of either impairment or improvement) are associated with changes in the correspondent brain regions called *neuroplasticity* [7]. Furthermore, training some skills can improve other related or even unrelated skills called *transfer* [8]. Although neighbour and similar untrained domains have more chance to benefit from transfer [9], far domains could gain from transfer effect [10]. There is some evidence showing that transfer effect can even occurred between physical and cognitive domains. This effect has been found in both correlational and interventional studies. For example, some studies suggest that, physically active people have better cognitive or academic performance compared to sedentary individuals [11-13]. Furthermore, both self-reported physical activity and objectively measured cardiovascular fitness at the baseline situation are considered as good predictors of cognitive performance [13-15]. The association of physical fitness and cognitive performance raise the chicken and egg question: Does exercise make people smarter, or do smarter people exercise more? Interventional studies provided some evidence on this issue and showed that aerobic training can improve executive functions [16, 17], attention [18], memory and affect [19].

Due to concurrent cognitive and physical deterioration in late life, the majority of these studies detect this interaction in older adults (Nejati, 1392; [20]). However, some studies on children have also shown that, objective measures of cardiorespiratory fitness are associated with behavioral measures of inhibitory control [21, 22], executive functions and attention [23]. For example, studies on children with attention deficit and hyperactivity disorder (ADHD) showed that physical activity appears as a compensatory mechanism for enhancement of cognitive functions. For example, the brain concentration of catecholamine neurotransmitters such as norepinephrine and dopamine increased after exercise in ADHD [24] which is similar to medication effects.

Generally, there are three hypotheses that explain the effects of exercise or physical activity, on executive control in terms of neurochemical modulation. Firstly, exercise leads to oxygen saturation [25] and angiogenesis [26] in the cortex that is important for cortical activities. Secondly, exercise increases the brain neurotransmitters, such as serotonin and norepinephrine, facilitating information processing [27, 28]. Finally, exercise can up regulate neurotrophins such as brain-derived neurotrophic factor (BDNF), insulin-like growth factor (IGF-I) and basic fibroblast growth factor (bFGF) that support neuronal survival and differentiation in the developing brain and dendritic branching and synaptic machinery in the adult developed brain [29].

In addition to exercise, cognitive rehabilitation with progressive graded tasks can also improve cognitive functions. The effectiveness of cognitive training to improve cognitive and executive functions in children with ADHD has been found earlier [30-35]. Cognitive training programs often are implemented by some sedentary tasks such as computerized tasks with minimal physical activity such as finger tapping.

To put it in a nutshell, both physical activity and cognitive rehabilitation have a significant effect on cognitive functioning. Combination of these training programs showed an added value for improvement of impaired cognitive functions[36-39]. This combination looks beneficial for children with ADHD whose have difficulty with sedentary/ boring tasks.

In the present study, a cognitive rehabilitation program in which some physical activities with specific cognitive demands namely exercise for cognitive improvement and rehabilitation (EXCIR) was used for rehabilitation of attention and executive function in children with ADHD.

Material And Methods

Participants. Thirty children with ADHD (age M = 10, SD =1.78), diagnosed by a child and adolescence psychiatrist according to the DSM-V criteria were participated in the study. Participants were randomly assigned into two equal experimental and wait-list control groups. None of participant was taking psychoactive medication (e.g., methylphenidate) when recruited and during the study. They did not report any neurological or psychiatric impairments or history of head injury, learning disorder and seizure. There are no significant differences between experimental and wait- list control group based on independent T-test for age ($T_{1,28}=1.241, p>.05$) and education ($T_{1,28}=1.121, p>.05$). Demographic information is shown in Table 1. The study was performed according to the latest version of the Declaration of Helsinki ethical

standards and approved by the local Institutional Review Board and the Ethical Committee of the local University. Given that participants were under legal age, their parents were instructed about conduct of the experiments. They then gave their informed consent before participation. Participants were free to withdraw from experiment at any phase.

Table 1: Demographic characteristics of participants

Variables	M(sd)/ Description
Age (year)	10 (1.78)
Education (year)	1.27 (.45)
Gender: male (female)	22 (8)

*Abbreviation:*M: mean, sd: standard deviation

Color- word Stroop task. A computerized version of the task was used for measuring selective attention. In this task, color words (red, green, blue, and yellow) were presented in different colors and participant had to press the correspondent color- key on the keyboard, given the ink of presented words. The color ink was in black (neutral), congruent, and incongruent in three different stages. The accuracy and reaction time of response were calculated for each stage and the interference score were calculated based on subtracting interference and control stage scores [40].

Trail Making Test. In the trail making task, subject had to connect a sequence of 25 consecutive targets on two sheets of paper. In the first sheet (part A), all targets are numbers (1, 2, 3, etc.) that should be connected sequentially. In the second sheet (part B), the numbers were displayed in two colors (red and blue) and the examinee alternates between the colors of numbers with sequential order (1 red, 1 blue, 2 red, 2 blue, etc.) [41].

Go-No/Go Task. In this task, participants are presented with stimuli in a continuous stream and they need to make a binary decision on each stimulus by pressing a button (Go) for a specific stimulus and not pressing the same button (No-Go) for a different stimulus. In this study, participants were presented with a plane, 7 cm in size and black in color, appeared on the screen in four directions up, down, left, and right. They were instructed to press the button aligned with the plane (the Go condition), but they had to withhold pressing any button when the sound “Beep” was heard (the No-Go condition). Participants were then asked to focus on a cross on the screen and to press a response button “as quickly and accurately as possible” to all Go stimuli. This task consisted of 100 stimuli that required response execution on 75% of trials, and the inhibition of a response on the remaining 25%. The dependent variables were accuracy for the Go and No-Go categories and reaction time of Go stimuli. It is notable that the correct response to No-Go stimuli examines the prepotent response inhibition which clearly measures inhibitory control compared to other outputs as participants had to refrain from pressing the arrow button when they heard beep with delay. This task took about 7 minutes to complete [42].

N-back Test. In order to measure working memory we used visual “N-back” task which is a widely used and accepted test of working memory and is arguably the current gold standard measure of WM in the cognitive neuroscience literature [43]. During N-back task participants are presented with a stimulus (letter or picture) one at a time on screen and they are asked to identify the picture that repeats relative to the one occurred n items before its onset. In our study, the target was any picture that was identical to the one it preceded in one trial back or in “1-back”. The task consisted of 100 stimuli and performing the task lasting around 5 minutes. We used response time and number of correct response as the task measures.

Attention registration task (ART): The ART is a letter cancellation task consisted of a test worksheet which specified the five target letters to be cancelled. This test sheet consisted of letters of the alphabet arranged randomly in 22 rows and 14 columns. The participants were asked to cancel as many target as possible and as fast as they could. The omission error (OE), commission error (CE), and total time (TT) were calculated as the test measures. This test takes around 30 minutes to complete [44].

Exercise for cognitive improvement and rehabilitation (EXCIR). The EXCIR consists of 12 exercise with progressive cognitive demands at 10 levels to improve cognitive functions such as interference control, sustained attention, cognitive flexibility, inhibitory control, and working memory (Table 2).

Table 2: Exercise for cognitive improvement and rehabilitation (EXCIR) tasks

No	Task Names	Description	Cognitive Demand
I	Color Jumping	To jump on a color cell in a table of colors given the meaning of some presented color words on the screen.	IC
II	Arrow Jumping	To jump on an arrow considering the direction of a small arrow within a large arrow with similar or dissimilar direction.	IC
III	Number Jumping I	To jump on a number grid in a table of numbers, if two presented number on two side of the screen were the same.	SA
IV	Pattern Walking	To walk on leaves with different color and number intermittently and ascendingly.	CF
V	Hand Movements I	To move a hand in response to hands image, moving upward or downward in two sides of the screen.	SA
VI	Slow Walking	To walk on a drawn pathway as slow as possible	OI
VII	Clap/ No-Clap	To clap with a single clap of clinician and do not clap with double clap of clinician.	PI
VIII	Limbs Movements	To move limbs in response to hand or feet images, moving upward or downward in two sides of the screen.	SA
IX	Calculation Walking	To walk on a footprints pathway and add the numbers written on the foot print that lay under the feet in each step.	WM
XI	Number Jumping II	To jump on smaller number in response to the two presented numbers with different amount and size.	IC
XII	Hands Movements II	To move the ipsilateral or contralateral hand in response to hands images in green or red, moving upward or downward in two sides of screen.	IC, SA

Abbreviation: IC: interference control, SA: sustained attention, CF: cognitive flexibility, OI: ongoing inhibition, PI: prepotent inhibition, WM: working memory

Figure 1: Schematic drawn of EXCIR tasks. The tasks name and explanation are presented in the table 1 with same Greek numbers

Statistical analysis. Descriptive statistics, including means and standard deviations of participants performances in experimental and control groups, are calculated at pre- and post-intervention stages and are shown in Table 1. Independent t tests were used to determine whether there were any systematic differences between the groups prior to the intervention. A series of 2×2 repeated measures multivariate analyses of variance (ANOVAs) were performed for evaluating effectiveness of interventions on participants' performance with group as the between subject factor (intervention vs control), time as the within-subjects factor (pre- intervention vs post- intervention), and the Group \times Time interaction effect. The interaction is the primary effect of interest, as a significant effect would support the idea that the 2

groups differ in their degree of change from pre-intervention to post- intervention. Our ANOVA met required assumptions of homogeneity of variances and normality.

We used repeated-measures ANOVAs to analyse a different set of conceptually related dependent variables. For each ANOVA, with significant overall multivariate Group \times Time effect, we conducted univariate repeated measures follow-up tests to examine the interaction effect separately for each dependent variable. We based the F ratios for each multivariate test on Wilks's approximation. We also calculated Pearson product-moment correlation coefficients to examine the linear relationships among the dependent variables included in each MANOVA.

Results

Table 1 shows the means and standard deviations for the test measures. Independent T- tests revealed no significant differences between the experimental and wait-list control groups for any of the pre intervention study variables.

The first repeated measures ANOVA performed for reaction time and accuracy of attention bias index. For reaction time, the multivariate tests for the MNOVA yielded a marginally significant main effect for time ($F_{1,56} = 3.438$, $p = .069$, $\eta^2 = 0.058$), a non- significant main effect for group ($F_{1,56} = .248$, $p = .620$, $\eta^2 = 0.004$), and a non significant Group \times Time interaction ($F_{1,56} = 4.194$, $p = .045$, $\eta^2 = 0.070$). For error, a non- significant main effect for time ($F_{1,56} = 2.258$, $p = .139$, $\eta^2 = 0.039$), group ($F_{1,56} = 5.892$, $p = .018$, $\eta^2 = 0.095$), and respected interaction interaction ($F_{1,56} = 7.912$, $p = .007$, $\eta^2 = 0.124$) were found.

The second test on the measures of trail making test, found a non- significant main effect for time ($F_{1,54} = 0.783$, $p = .380$, $\eta^2 = 0.014$), and group ($F_{1,54} = .208$, $p = .208$, $\eta^2 = 0.029$), but a significant respected interaction ($F_{1,54} = 4.755$, $p = .034$, $\eta^2 = 0.081$) for the part A. The part B- A analysis yielded a non- significant main effect for time ($F_{1,54} = 0.136$, $p = .714$, $\eta^2 = 0.003$) and group ($F_{1,54} = 1.333$, $p = .253$, $\eta^2 = 0.024$), but a significant respected interaction ($F_{1,54} = 4.284$, $p = .043$, $\eta^2 = 0.074$).

The third test on Go/ No- Go test, found a non- significant main effect for time ($F_{1,56} = .230$, $p = .633$, $\eta^2 = 0.004$), group ($F_{1,56} = 1.437$, $p = .236$, $\eta^2 = 0.025$), and respected interaction ($F_{1,56} = .920$, $p = .343$, $\eta^2 = 0.016$) for reaction time of Go- stage. For no go stage, a non- significant main effect for time ($F_{1,56} = 1.067$, $p = .633$, $\eta^2 = 0.004$) was found but the effect for group ($F_{1,56} = 18.276$, $p = .001$, $\eta^2 = 0.246$), and the interaction of Group \times Time ($F_{1,56} = 16.994$, $p = .001$, $\eta^2 = 0.233$) were significant.

The forth ANOVA analysis on accuracy, as the main grade of N- back task, yielded a significant main effect for time ($F_{1,54} = 6.117$, $p = .017$, $\eta^2 = 0.102$), group ($F_{1,54} = 5.283$, $p = .025$, $\eta^2 = 0.089$), and respected interaction ($F_{1,54} = 19.303$, $p = .001$, $\eta^2 = 0.263$). For the time consuming for performing the task, a non-

significant main effect for time ($F_{1,54} = 7.765, p = .007, \eta^2 = 0.126$), group ($F_{1,54} = .057, p = .812, \eta^2 = 0.001$), and respected interaction ($F_{1,54} = .280, p = .599, \eta^2 = 0.005$) were shown.

The final ANOVA performed for measures of attention registration test including OE, CE, and TT. For OE, a significant main effect for time ($F_{1,55} = 9.614, p = .003, \eta^2 = 0.149$), and group ($F_{1,55} = 7.652, p = .008, \eta^2 = 0.122$), but a non-significant interaction ($F_{1,55} = 10.654, p = .002, \eta^2 = 0.162$) were found. For CE, the main effect for time ($F_{1,55} = 1.469, p = .231, \eta^2 = .026$), group ($F_{1,55} = 3.626, p = .062, \eta^2 = .062$), and their interaction ($F_{1,55} = .854, p = .360, \eta^2 = .015$) were non-significant. For TT, a significant main effect for group ($F_{1,55} = 8.448, p = .005, \eta^2 = .133$) but non-significant main effect for time ($F_{1,55} = .081, p = .777, \eta^2 = .001$) and respected interaction ($F_{1,55} = .059, p = .809, \eta^2 = .001$) were revealed.

Table 1: mean and standard deviation of the tests score in the study groups

Measurements	<u>Intervention Group</u>		<u>Control Group</u>	
	Pre- test M (SD)	Post- Test M (SD)	Pre- test M (SD)	Post- Test M (SD)
Trial Making Test (TMT)				
TMTB (s)	117.71 (80.93)	80.93 (35.66)	106.85 (39.19)	122.40 (60.71)
TMTB-A (s)	42.85 (25.14)	21.73 (18.56)	34.92 (35.30)	49.66 (45.86)
Persian Attention Registration Test (PART)				
Omission Error	39.57 (19.67)	8.40 (5.74)	37.13 (22.56)	37.93 (22.07)
Commission Error	7.57 (13.14)	2.13 (2.09)	10.06 (11.06)	9.33 (9.37)
Total Time (s)	1311.07 (631.05)	1257.33 (220.14)	989.80 (309.01)	985.60 (296.85)
Stroop Test				
Accuracy	73.43 (21.18)	52.03 (12.13)	64.93 (26.52)	66 (22.46)
Reaction Time (ms)	3 (2.33)	1.13 (0.61)	2.83 (1.96)	3.40 (1.24)
1- Back				
Accuracy	15 (5.09)	22.86 (3.11)	17.40 (3.94)	15.20 (15.04)
Time	203.09 (82.66)	146.76 (38.39)	198.16 (68.35)	159.81 (63.87)
Go Nogo				
Go- Accuracy	21.13 (1.92)	20.33 (2.52)	21.26 (2.15)	21.53 (1.95)
Go- Reaction time	0.95 (0.21)	0.88 (0.21)	0.95 (0.21)	0.88 (0.21)
Nogo Accuracy	13.46 (6.34)	24.46 (1.06)	15.73 (5.67)	15.93 (5.41)

Conclusions

The present study was aimed to investigate the effectiveness of EXCIR on the improvement of attention and executive function in children with ADHD. In this study, we used goal- directed physical activity as environmental modification for cognitive training. Results showed a significant effect of EXCIR on the

improvement of cognitive flexibility, sustained attention, selective attention, inhibitory control, and working memory implicating that cognitive rehabilitation through goal-directed modification in environment, leads to purposeful alteration in cognitive abilities.

Previous studies showed effectiveness of either physical activity [45, 46] and cognitive training [30-35] on the improvement of cognitive functions particularly executive functions. Although enhancing effects of physical activity on cognitive functions have been documented [47, 48], there is intriguing evidence that physical activity in a cognitively-engaging context has a stronger impact on cognitive functions especially executive functions [49]. For example, exercises that engage executive functions such as aerobic exercise [49, 50] require the same cognitive processes of executive functions tasks like strategic and goal-directed behavior in the face of a novel game experience. This implicates that purposeful physical exercises that engage cognitive functions of interests would be more effective and long-term and this is the idea behind the EXCIR.

The fact that should be mentioned here is that physical activity and cognitive training interact at several levels. Physical activity or movement should be considered as an output of cognitive processing. Each movement has two components namely mental and physical. Mental component involves cognitive processes that are required for proper planning and performing of the physical component. Although the motor control problem ignored in the majority of neurodevelopmental disorder, these children have lower performance on standardized motor tests, comparing to typically developing children [51-53]. This impairment is not related to physical component of movement, but the impairment is latent in cognitive demand of movement.

Motor impairment during childhood can lead to a range of psychosocial, emotional, academic and physical problems [54-56]. In the case of ADHD, physical activity is more important due to its hyperactive nature. Improving effects of physical activity on reducing symptoms of children with ADHD has been reported in some studies [57]. Another study found that physical activity enhances some executive functions in children with ADHD including working memory and shifting attention based on performance on the digit span test and the letter-number sequencing task respectively [58]. Our study showed similar improving effect on working memory measured by 1-back task and cognitive flexibility assessed by color trial making task. The difference between two methods is related to the physical and cognitive demands of the tasks. The EXCIR requires lower level of physical activity and at the same time higher level of cognitive demand compared to general aerobic physical activity. This means that EXCIR actively and purposefully engages cognitive functions of interest that we intend to improve.

Although improving effects of physical activity on cognitive functions have been reported earlier however, it seems that general physical activity may improve cognitive functions in general rather specific domain. This factor become important in the light of prescription of exercise for individuals with well-known and specific cognitive impairment. For example, a preliminary study revealed that acute exercise leads to improved performance on the Stroop test, but not on the trail making and digit span tests in college students with ADHD. In this study, students without ADHD showed an enhancement in more domains of

executive functions including inhibitory control, shifting attention and working memory assessed by Stroop, trial making, and digit span tests. Furthermore, brain derived neurotrophic factor increased only in students with ADHD after acute exercise [59]. This implicates that individuals with ADHD that have particular cognitive deficits may not benefit enough from acute exercise compared to normal ones.

The difference between mentioned studies that used physical exercise and our study which applied a more purposeful and cognitively-engaging exercise underlies the type of physical activity; previous studies used general physical activity without planned cognitive demands and mostly emphasized on the aerobic exercise that increases cardiovascular activity. A meta-analysis of 37 studies revealed that cardiovascular capacity (VO2 Max) cannot solely explain the positive effect of physical activity on cognitive performance [60]. Therefore, the beneficial effect of exercise is not related to the excessive physical activity. Furthermore, some studies found that dyslexic children have gained more cognitive improvement from simple exercise such as balance challenging, co-ordination and timing than aerobic physical activity used for cardiovascular fitness [61] implicating that specific, rather than general physical activity are more beneficial in populations with particular cognitive impairments.

It seems that the cognitive demand of physical activity is more important than physical demand and exercises that are more cognitively engaging are more beneficial than less cognitively-engaging exercises. There could be some explanations for this. First of all, the degree that an exercise engages cognition in general and executive functions in particular is an important factor. The EXCIR positively affects executive functions and their supporting neural circuitry in the prefrontal cortex [49] as these exercises are based on the executive function tasks that are based on goal-directed behavior rather than on automatic behavior elicited in an associative learning manner. The EXCIR requires participants to create, monitor, and modify a cognitive plan to meet task demands and thus like the executive function training tasks (e.g., Go/No-Go, N-back, Stroop task) require similar way of thinking and similar cognitive tasks. For example, an exercise that requires a child with ADHD moves his/her hand after specific stimulus but not any, involves selective attention and inhibitory control more than general physical activity.

Furthermore, basis on transient hypo- frontality hypothesis that state severe acute exercise has a detrimental effect on brain activity [62] which may explain why acute exercise may not benefit executive dysfunctions in ADHD. The brain has a limited capacity to processing (Broadbent, 1958) as well as limited nutritional resources including cerebral blood flow, oxygen and glucose [63] and competitive nature of brain activities [64] leads to directing energy resources to sensory- motor cortex that is essential for performing physical activity [65] explaining why acute exercise has detrimental effects on the brain activity. After such phenomenon following acute exercise, the prefrontal area that is not critical for physical activity but for executive functions has lower activity [66]. The EXCIR tasks utilize mild physical activity with graded purposeful cognitive activity to aggregate the beneficial effect of both physical and cognitive exercises. Furthermore, in the physical activity training, the progression as a main component of training is applied through increasing the the severity of physical activity that may be is not important for cognitive improvement[67]. In the EXCIR package however, the progression embedded in the cognitive part of exercise with the same physical activity demand.

We can conclude that combination of physical activity with cognitive training is beneficial in cognitive training enabling subjects to use the beneficial effect of both of physical and cognitive training. This has promising implications for improving cognitive deficits in patients suffering from cognitive deficits. Results of the present study can be used to take the first few steps in designing cognitively engaging exercises that are not only effective in physical fitness but also in cognitive fitness benefitting the field of cognitive rehabilitation, cognitive neuroscience and cognitive psychology.

The main limitation of present study was lack of active control group for physical activity without progressive cognitive exercise which could help us to better differentiate between physical and cognitive components of our interventions. Moreover, it should be noted that participants of our study were children with ADHD which does not allow us to generalize the findings to other populations. Future studies are suggested to apply the EXCIR paradigm in other populations suffering from cognitive dysfunctions as well as normal populations.

Declarations

Ethical Considerations. All procedures performed in studies involving human participants were in accordance with the ethical standard of the national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Informed consent was obtained from all individual participants included in the study. The procedure approved by ethical committee of Raftar cognitive neuroscience research centre.

Availability of data and material. Data of the study are available for researcher on request through email to the author.

Competing interests. The author declares that they have no competing interests.

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Authors' contributions. V.N. wrote the manuscript and analyzed the data. FF gathered the data.

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Figures

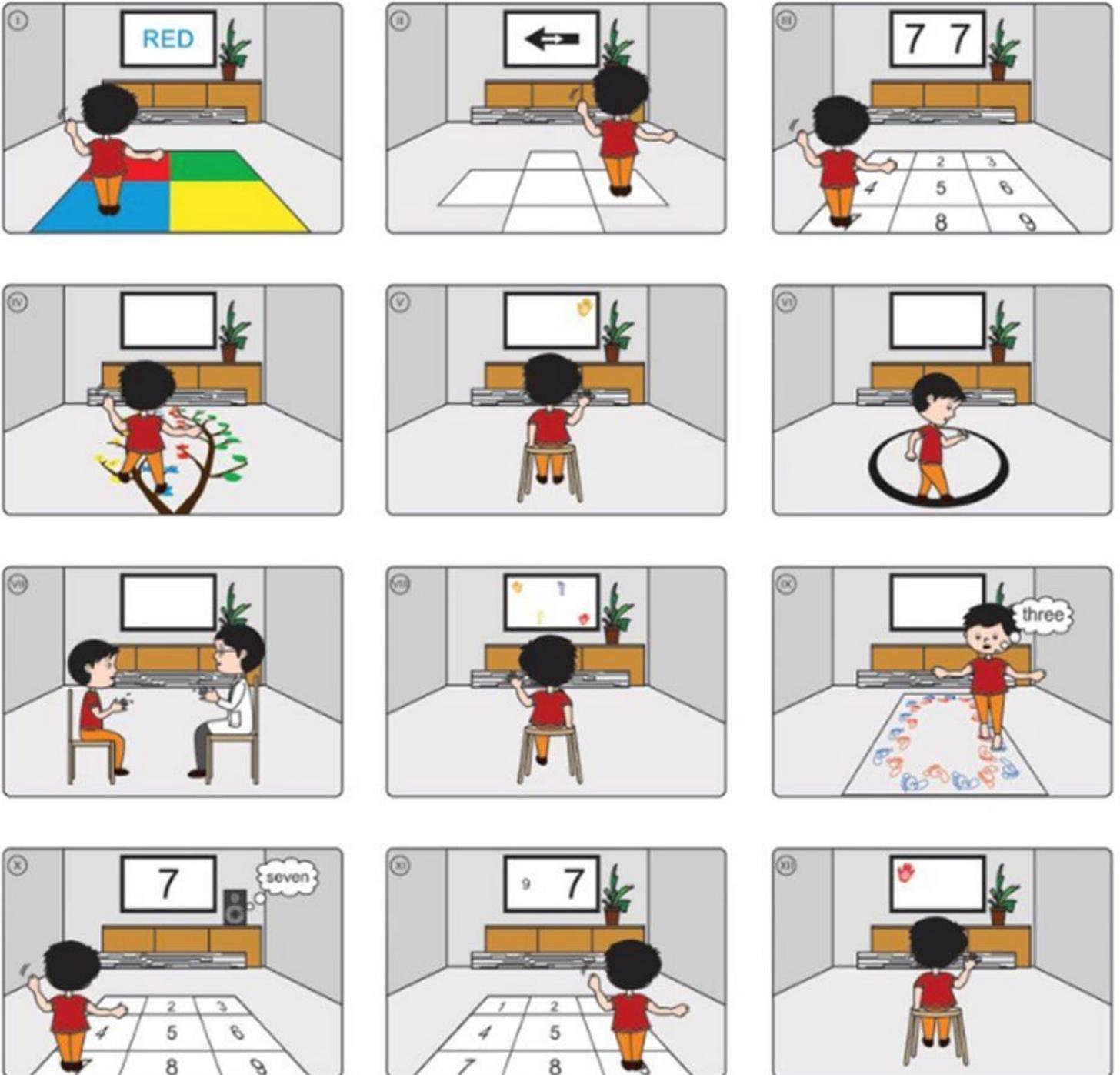


Figure 1

Schematic drawn of EXCIR tasks. The tasks name and explanation are presented in the table 1 with same Greek numbers