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Effects of the special olympics unified sports soccer training program on executive function in adolescents with intellectual disabilities

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1. Introduction

Intellectual disability (ID) encompasses a broad range of developmental disorders characterized by limited intellectual capacity, an IQ below 70, and poor adaptive behavior.[1] ID is the most common neurological developmental disorder, with a worldwide incidence of ∼ 1–3%.[2] In mainland China, 11,820,000 people were diagnosed with ID in 2007, of whom 954,000 were younger than six years old.[3] Individuals with ID have significant deficits in attention, learning, memory, executive functions, language,[4] functional autonomy (i.e., the ability to independently perform tasks of daily living, including basic and instrumental activities), and social inclusion.[5,6] These deficits negatively impact the quality of life their quality of life.[7] Individuals with ID incur annual costs in terms of health costs, disability support, lost income and other social costs of US$172 000, accumulating to many millions of dollars over a lifetime.[8] The Special Olympics (SO) is commonly cited to play an important role in the lives of individuals with intellectual disabilities (ID). The SO was established in 1968 with the aim of providing sport training and athletic competition opportunities for individuals intellectual disability (ID).[9] The organization's programs, spanning 200 countries as reported in the 2019–2020 Annual Report, support over 5 million athletes, 500,000 coaches, and 1 million volunteers, and facilitate 100,000 competitions. The Special Olympics (SO) Unified Sport (UNS) is intended to provide children with and without ID continuing opportunities to develop physical fitness, skills and friendship with other SO athletes, their partners and the community.[10] Soccer, the most popular sport globally,[11] is a critical component of the UNS soccer training program. This international soccer training and competition program is specifically designed for individuals with ID and aims to improve their physical fitness, health, motor skills, self-confidence, and social skills, ultimately enhancing their quality of life.[12] Previous studies proved that the UNS program has positively affected the attitude,[13] fitness and soccer skill performance,[14] attention and social behavior, and decrease aggression, anxiety and depression levels.[15] The reason for this phenomenon is still unclear to us. Due to the low intelligence of ID individuals, with severe impact on the quality of life of affected individuals and their families, and high social costs.[16] Factors associated with improving quality of life for people with ID deserve further exploration.

Executive function is a significant predictor of psychosocial quality of life,[17] research into how to improve executive function could help improve the quality of life for this group. Executive dysfunction is common in individuals with ID.[18–21] Executive function (EF) refers to a set of higher-order functions that organize and regulate goal-driven behavior, involving several brain regions, including the prefrontal cortex.[22] Diamond notes there is general agreement that there are three core EFs: (1)Inhibitory control, including self-control (behavioral inhibition) and interference control (selective attention and cognitive inhibition)]; (2)Working memory that holds information in mind and works with it; and (3) Cognitive flexibility is adapting cognitive behavior to changing demands or priorities.[23] Previous studies have confirmed that these three EF components are impaired in ID adolescents.[18–21] It is crucial to assess the executive function (EF) profile in people with intellectual disability (ID). EF skills have a significant impact on academic performance, social skills, and overall health outcomes in typically developing children. In children with ID, EF skills are also critical for

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school participation, academic achievement, and future employment opportunities. Therefore, it is essential to identify and support the EF needs of individuals with ID.[19,24,25] Deepening our knowledge about executive function and finding simple and feasible ways to improve it in adolescents with ID could help researchers, clinicians, caregivers, and parents improve interventions and help people with ID and their families enhance their quality of life.[26] Meta-analysis confirms that chronic exercise intervention may promote multiple aspects of executive functions.[27] A systematic review of Charles Hillman suggested that physical activity or habitual physical activity could strengthen functional connections of the human brain, which may improve various domains of executive function.[28] And according to a randomized clinical trial, a 20-week aerobic exercise program modulates the frontal lobe activity, which might provide a positive influence on working memory and inhibitory control in children with overweight/obesity.[29] According to several meta-analyses, ID individuals tend to have lower levels of physical activity and poorer mental health than their typically developing peers. Interestingly, Physical activity positively affects mental health, including psychological and cognitive function, in children and adolescents with IDs.[30,31] However, according to current research, it is unclear how exercise improves cognitive function by improving brain structure and function. Several meta-analyses have demonstrated the effects of physical activity on executive function (EF) in children and adolescents with and without special educational needs, such as ADHD and ASD.[32–34] However, Adele Diamond suggests that most current studies lack consideration of important factors, such as a control group, fluid intelligence, dose, duration, motivational status, modality, and intensity of physical activity. These factors must be considered to determine when and how physical activity improves EF. Moreover, there is a lack of evidence regarding the neural mechanisms underlying EF improvement following physical exercise intervention.[35] There needs to be more research investigating the executive functioning of individuals with ID engaged in sports,[36] as most studies have primarily focused on motor skills and physical fitness.[37]

Evidence from neuroimaging studies suggests that EFs depend on prefrontal cortex (PFC) and other interrelated neural regions. Previous studies have shown that the DLPFC is the main area of the brain's control executive network and is related to cognitive inhibition and working memory.[38,39]The 2-back task activates FPA and VLPFC,[40,41] and that VLPFC plays an essential role in working memory.[42] Therefore, we choose six region of interest (ROI) based on the Brodmann area, including left frontopolar area (L-FPA), right frontopolar area (R-FPA), left dorsolateral prefrontal cortex (L-DLPFC), right dorsolateral prefrontal cortex (R-DLPFC), left ventrolateral prefrontal cortex (L-VLPFC), and right ventrolateral prefrontal cortex (R-VLPFC). Functional near-infrared spectroscopy (fNIRS) is widely adopted in cognitive neuroscience to measure the cortical oxyhemoglobin concentration in real-time, reflecting the individual brain activation status.[43] Because of portability, low cost, strong noise resistance and high temporal resolution, fNIRS could be used to evaluate the cerebral hemodynamic characteristics of healthy and impaired people.[44,45] To record participants' brain activities when they were anticipating or performing executive tasks, we used functional near-infrared spectroscopy. In our study, behavioral performance and brain activation were tested for differences between groups to investigate whether the UNS soccer program improves executive function. We hypothesized that the UNS soccer group would exhibit better behavioral performance and brain activation than the control group in three EF tasks. To provide valuable insights into the potential benefits of the Special Olympics UNS soccer training program for executive function in adolescents with ID and promote the development of Special Olympics practices.

2. Materials and methods

2.1. Participants

The sample size of each group calculated by PASS 15 software was 17 cases to provide 80 % power with a two-sided alpha value of 0.05 (test for two-independent sample *t*-test). Given an anticipated 20 % dropout rate, the minimum required sample size was 41 participants. Fifty-eight participants were recruited from five special education schools in Guangzhou Province, China. All of the participants in the soccer group were selected from the UNS soccer program. According to the Edinburgh Handedness Questionnaire (Oldfield, 1971), all subjects were right-handed and had normal or corrected-to-normal vision. The study procedures were carried out following the Declaration of Helsinki. The study protocol was approved by the Guangzhou Sport University Ethics Committee (approval no.: 2021LCLL-15) and registered by The Chinese Clinical Trial Registry (registration no.: ChiCTR2100054719). The participants' parents were informed about the study and provided informed consent.

Inclusion criteria: (1) All subjects were adolescents aged 12–18 years with hospital-diagnosed mild ID based on the fourth edition of the Wechsler Intelligence Scale for Children (intelligence range: 50–69), (2) normal visual acuity or corrected visual acuity, (3) no other comorbidities or neurological disorders, and (4) did not participate in similar psychological experiments for six months.

Exclusion criteria: (1) Participants who regularly participated in cognitive training and (2) were unable to understand EF tasks. We recruited 58 adolescents, 7 students in the football group and 6 students in the control group were excluded from the study due to their inability to understand or complete any task. After eliminating 13 participants who could not understand the tasks, 44 subjects remained, comprising 18 in the soccer group and 26 in the control group.

Experimental grouping: Long-term exercise was defined as regular exercise several times a week for at least six weeks.[46] The participants of the soccer group in this study were recruited from the UNS soccer program in Guangzhou. They practiced soccer for one and a half years, from October 1, 2019, to March 30, 2021. They underwent soccer training 3 to 5 times a week, supervised by physical education teachers. Each session lasted for about 60 min. On the other hand, the control group consisted of adolescents with intellectual disabilities who did not have any regular exercise habits for six months.

2.2. Experimental procedure

For adolescents who met the inclusion criteria, demographic data were collected by questionnaire after their parents signed the informed consent form before the experiment. The experimental tasks began three days after the end of the soccer program and continued for one week. Before starting the tasks, we placed the functional near-infrared spectroscopy (fNIRS) devices on the subjects' heads. Sessions lasted approximately 40 min. Three tasks were randomly assigned. Participants had a short break after each task.

2.3. Measures

2.3.1. EF task

1. Flanker task

We use a modified Eriksen flanker task to assess inhibitory control in adolescents with ID.[47] In the Flanker task, the average response time and accuracy rate of consistent conditions, inconsistent conditions and conflict effects were used as outcome variables to reflect behavior performance. At the beginning of the task, an 800 ms fixation point was displayed on the screen, followed by a 2000 ms stimulus, with each stimulus presenting five fish in a horizontal array (i.e., 

or) in the centre of the computer screen. The rest time was 15 s before the next stimulus. Participants had to estimate the direction of the central fish and press the F or J key on a computer keyboard as quickly as possible (F if the central fish swam to the left, J if to the right). The target fish and the flanker fish pointed in the same direction in the congruent condition and in the opposite direction in the incongruent condition, 20 trials for each condition. For the Flanker task, we removed reaction times below 300 ms. Thirty-eight adolescents with intellectual disabilities (17 people from the soccer group and 21 people from the control group) completed the Flanker task.

2. 2-Back task

The 2-back task was used to measure working memory.[48] To evaluate behavioral performance, the 2-back task employs two outcome measures: average response time and accuracy. In this task, subjects were asked to remember one to nine random numbers and press the keyboard as quickly and accurately as possible to determine whether each number matched the number before the two trials (2-back number). If the number matched the 2-back number, the F key was pressed; if not, the J key was pressed. Each stimulus was presented for 300 ms red fixation cross followed by a stimulus number of 4000 ms, with an interval of 700 ms between each trial, resulting in an average total trial time of 5000 ms. In this paradigm, the practice experiment comprising 14 trials. The formal experiment was separated into two blocks. Each block had 14 trials, of which the first two were nonresponsive. Keys were pressed from the third trial on, and each trial randomly presented numbers. Each block had a 20 s rest period before starting and ending. The 2-back task was completed by 17 adolescents with intellectual disabilities in the soccer group and 20 in the control group.

3. Modified dots–triangles task

Subjects' cognitive flexibility was assessed using a modified version of the dots–triangles task,[49] in which a varying number of red or green smileys appeared on the screen in a 4 × 4 grid (i.e., three to eight smileys per half of the grid, equally distributed). Participants needed to respond to these quickly on the keyboard. The experiment included two block. The first block is repetition condition, includes two parts. The first part is a red smiley task, which required participants to press the F or J key, depending on which part of the screen (left or right) had more red smiley faces. The second part was the green smiley face task (block 1: 20 practical trials and 40 experimental trials). The second block is shifting conditions. Participants had to decide whether there were more smiley faces at the top or bottom of the grid(block 2; 10 practice trials, 30 experimental trials). Each trial appeared with a fixation point of 800 ms, and the stimulus remained on the screen for 2000 ms until the response was given. Participants had a 20 s rest after 10 trials. 17 people from the soccer group and 18 people from the control group understood the Modified dots-triangles task. In the Modified dots–triangles task, the average response time and accuracy of the repetition condition, shifting condition, and shifting cost are used as outcome variables to reflect behavior performance.

2.3.2. Physical activity measured

Physical activity is defined as bodily movement produced by skeletal muscles with energy expenditure (varying continuously between low and high levels).[50] Habitual physical activity refers to the broad concept of engaging in physical activity or exercise on a regular basis.[51] Habitual physical activity levels were evaluated by using a questionnaire that focuses on habitual exercise and non-exercise physical activity performed during the prior three months.[52] The Physical Activity Questionnaire for Older Children (PAQ-C) consists of 10 items assessing the frequency of participation in different types of physical activity in the last seven days (i.e., during physical education classes, at recess, at lunchtime, right after school, in the evenings, on weekends, and during leisure time). Items 2–8 were answered on a five-point Likert scale [1 (lowest) to 5 (highest)]. The mean self-reported physical activity score was further categorized into low (<2.33), moderate (2.33–3.66), and high (>3.66). We followed the categorization of a previous study that used the PAQ-C.[53] According to previous research, the reliability for the PAQ-C ranged from r = 0.75 to 0.82, and internal consistency reliability values (coefficient alpha) ranged from 0.79 to 0.89.[54] In this study, reliability for the PAQ-C in this sample was high internal consistency (Cronbach's alpha = 0.815).

2.4. fNIRS data acquisition

The fNIRS data were acquired using the NIRSport system (NIRx Medical Technologies, LLC, New York, USA). Probe-channel sets were installed with reference to the cap (EASYCAP, Herrsching, Germany) and then placed on the participant's head. The probes were arranged according to a 10–10 system forming 20 channels, with some adjustments to ensure that each emitter was 3 cm from its corresponding detector. The cap was positioned on the head by centring the bottom of the probe at the Fpz position (Fig. 1). We choose the region of interest (ROI) based on the Brodmann area. The six ROI comprised the left frontopolar area (L-FPA; channels 2, 4, and 5), right frontopolar area (R-FPA; channels 1, 8, and 9), left dorsolateral prefrontal cortex (L-DLPFC; channels 6, 7, 12, and 19), right dorsolateral prefrontal cortex (R-DLPFC; channels 10, 11, 14, and 20), left ventrolateral prefrontal cortex (L-VLPFC; channels 13 and 16), and right ventrolateral prefrontal cortex (R-VLPFC; channels 15 and 17). Each participant rested for at least 15 s (baseline) before executive tasks began or after each stimulus to avoid incoherent activation. fNIRS measurements were performed in a dark, quiet room. Participants were informed that they should not take analgesics 72 h before the experiment.

2.5. fNIRS data processing

Data analysis was made by the nirsLAB analysis package (v2017.06, NIRx Medical Technologies, LLC, Los Angeles, CA, USA). Discontinuities were automatically corrected or deleted by nirsLAB (std. threshold = 5). Then, according to Remove Spike Artifacts GUI of nirsLAB, motion artifacts were removed from the signal. A bandpass filter was used; 0.01 Hz was used to remove drift, and 0.01–0.1 Hz was used to filter respiratory noise. We used the modified Beer–Lambert law (Cope et al., 1988) to analyze the optical data from the fNIRS system. Changes in oxygenated hemoglobin (Oxy-Hb), deoxygenated hemoglobin (deoxy-Hb), and total hemoglobin (total-Hb) concentration data were collected at a sampling rate of 7.81 Hz.

2.6. Statistical analyses

EF task demographic data and behavioral data were analyzed using independent samples t-tests and Mann-Whitney *U* test (two-tailed). Normally or approximately normally distributed continuous variables were described as mean ± SD and compared by the independent samples t-tests. Otherwise, variables with obviously skewed distribution would be presented as median (1st quartile, 3rd quartile) and compared by Mann-Whitney *U* test. Hotelling's T2 test was used to determine whether there were significant differences in Oxy-Hb in the six ROI of the prefrontal cortex between the two groups in the three EF tasks ($p < 0.05$, after correcting for multiple comparisons).[55] Finally, to examine the brain-behavior relationship, we conducted Pearson's correlation analysis on the behavioral results and brain activity. All data were analyzed using IBM SPSS Statistics 26. P values were adjusted for multiple testing using Benjamini-Hochberg correction [false-discovery rate (FDR)-adjusted P value], where a FDR $p < 0.05$ was considered significant.

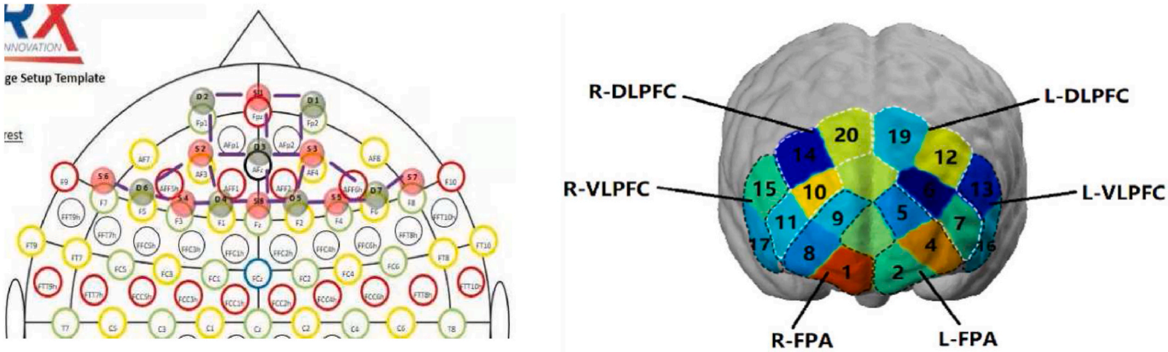

Fig. 1. **(Left)** Topographical layout of the NIRx headband. Sources are depicted in red and detectors in blue. Purple lines represent each channel. **(Right)** Coverage of the headband on the ICBM 152 head model. The color shadings do not have any meaning. L-FPA: left frontopolar area; R-FPA: right frontopolar area; L-DLPFC: left dorsolateral prefrontal cortex; R-DLPFC: right dorsolateral prefrontal cortex; L-VLPFC: left ventrolateral prefrontal cortex; and R-VLPFC: right ventrolateral prefrontal cortex.

3. Results

3.1. Participant characteristics

We recruited 44 adolescents with hospital-diagnosed mild ID (IQ: 50–69), including 18 in the soccer group (mean age: 14.61 ± 1.65 years) and 26 in the control group (mean age: 14.65 ± 1.49 years). The soccer group participated in soccer training for 22.43 ± 7.99 months, with a weekly training frequency of 3.71 ± 0.47 times and a training time of 1.59 ± 0.51 h. Height ($t = -3.232$, $p = 0.002$) and PAQ-C scores ($t = -2.334$, $p = 0.025$) were higher in the soccer group than in the control group, while there were no significant differences in other indicators (see Table S1 for details).

3.2. Behavioral performance

For the Flanker task, 2-back task, and the Modified dots–triangles task we removed reaction times below 300 ms. Fig. 2 presents the two groups' dots–triangles and the 2-back tasks performance differences. In the dots–triangles task, the accuracy of shifting conditions was higher in the soccer group than in the control group ($t = -2.060$, $p = 0.046$, Fig. 2A), and the accuracy of shifting cost was lower than in the control group ($t = 2.438$, $p = 0.020$, Fig. 2B), but there was no significant difference in response time. In the 2-back task, the accuracy of the soccer group was higher than in the control group ($t = -2.123$, $p = 0.041$, Fig. 2C). There were, however, no significant differences in response times between the two groups in the 2-back task ($t = 0.372$, $p = 0.713$). In the Flanker task, there was no significant difference between the soccer Group(0.10 [0.00, 0.27] and control Group(0.10 [0.00, 0.18])for the accuracy of the conflict effect. Similarly, no significant differences were found between both groups for the accuracy of congruent condition (0.65[0.53, 1.00] vs. 0.55 [0.40, 0.80]) and incongruent condition (0.58 ± 0.25 vs. 0.48 ± 0.23). Furthermore, we did not find a significant difference in response time for the conflict effect between the two groups (202.25 ± 222.09 vs. 227.03 ± 250.23). In addition, the soccer group and control group had no significant differences in congruent or incongruent conditions (for the congruent condition:1356.25 [1031.34,1578.41] vs. 1268.09 [877.03,1599.87]; for the incongruent condition: 1493.00 [1283.61, 1794.14] vs. 1405.18 [995.44, 1799.14] see Table S2 for details).

3.3. fNIRS analyses

There was marginal significance in the six ROI of the prefrontal cortex for the two groups during the dots–triangles task (Hotelling's trace = .505, $F(6, 28) = 2.358$, $p = 0.057$). Oxy-Hb activation in R-DLPFC decreased in the dots–triangles task in both groups, and Oxy-Hb in R-DLPFC was significantly higher in the soccer group than in the control group ($F = 4.660$, $p = 0.038$, FDR corrected $p = 0.23 > 0.05$, Fig. 3D). The 2-back task showed significant differences in the activation of the six brain regions in the prefrontal cortex between the two groups (Hotelling's trace = .519, $F(6, 30) = 2.596$, $p = 0.038$). Oxy-Hb measurements of the exercise group were lower than in the control group for the right frontal pole area (R-FPA; $F = 9.919$, $p = 0.003$, FDR corrected $p = 0.02 < 0.05$, Fig. 3E) and R-VLPFC during the 2-back task ($F = 4.278$, $p = 0.046$, FDR corrected $p = 0.14 > 0.05$, Fig. 3F). In the flanker task, there was no significant difference in overall PFC activation between the two groups (Hotelling's trace = .201, $F(6, 33) = 1.105$, $p = 0.38$, see Table S3 for details). Not all subjects completed all the tasks, reflected in the presence of different degrees of freedom reported from

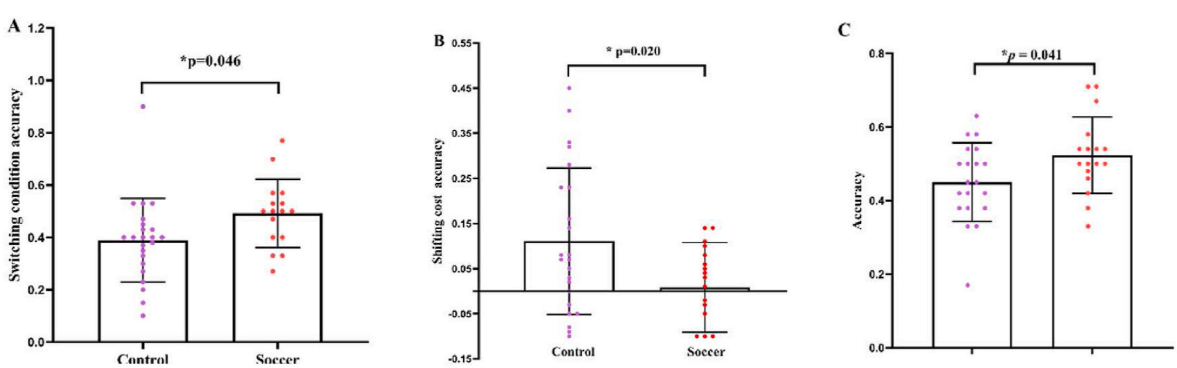

Fig. 2. Differences in accuracy in the dots–triangles and the 2-back tasks. A and B show the accuracy of the shifting conditions and shifting costs in the two groups, respectively, in the dots–triangles task. C shows the accuracy of the two groups in the 2-back task.

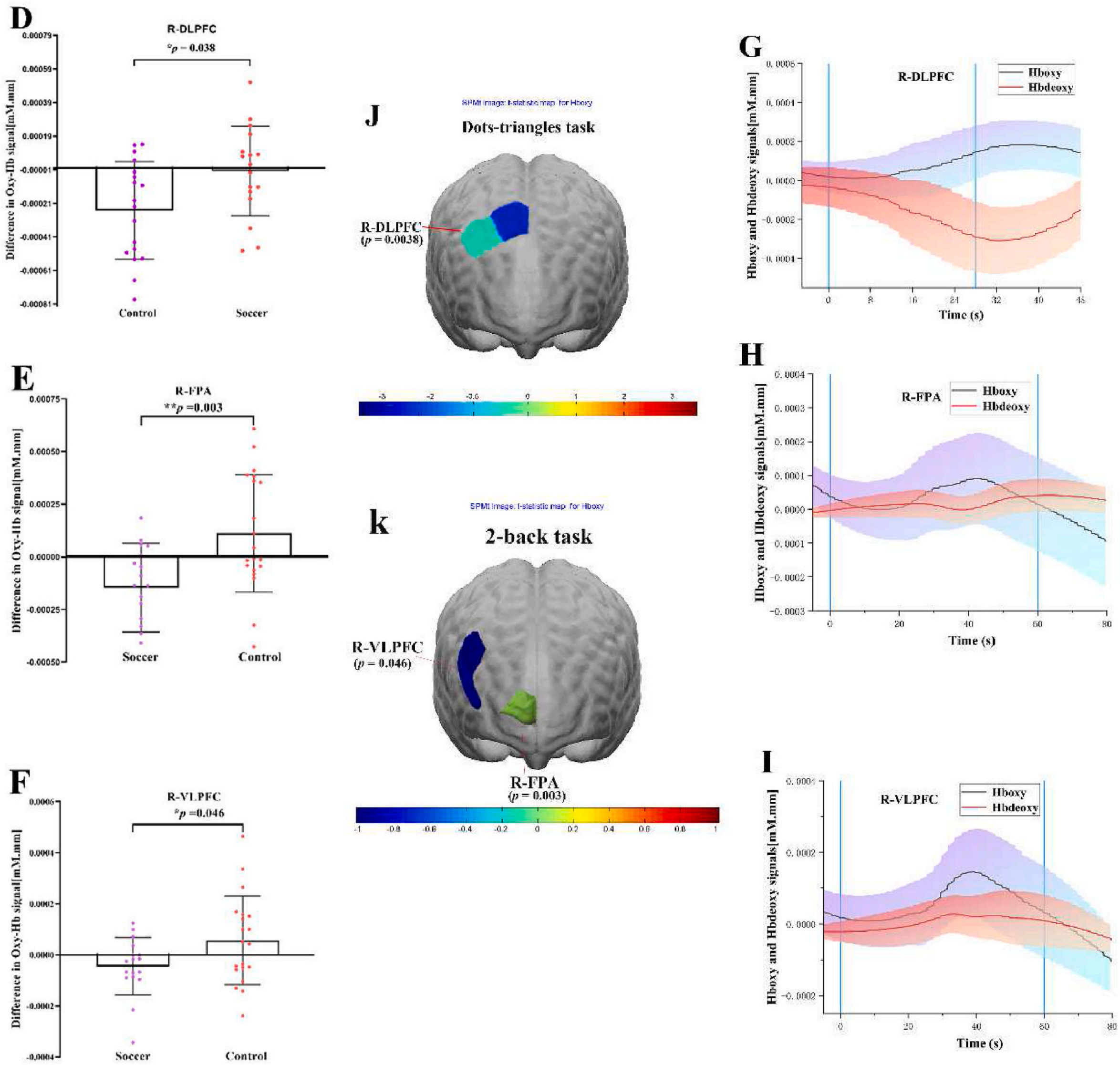

Fig. 3. Comparison of prefrontal cortex Oxy-Hb measurements between two groups of the dots–triangles and 2-back tasks. D: Oxy-Hb measurements of R-DLPFC of the two groups in the dots–triangles task. E, F: Oxy-Hb measurements of R-FPA and R-VLPFC of the two groups in the 2-back task. G, H, I: Waveforms of Oxy-Hb (black line) and deoxy-Hb (red line) signals in the dots–triangles task (G) and 2-back task (H, I). J, K: t-map of Oxy-Hb signal contrast activation in the dots–triangles and 2-back tasks, respectively; color bars show T-values.

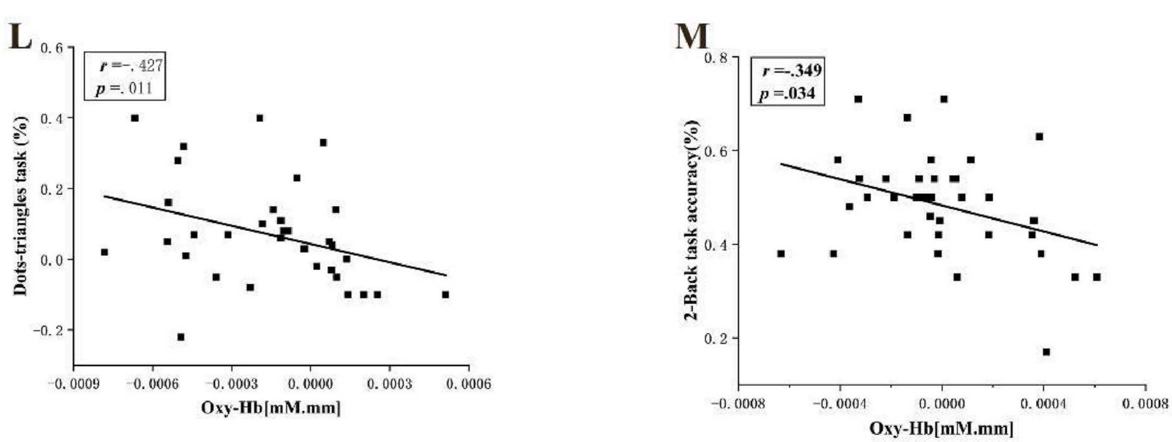

Fig. 4. Relationships between behavioral performance and Oxy-Hb measurement of the prefrontal cortex in the dots–triangles and 2-back tasks. L: Relationship between the accuracy of the dots–triangles task and Oxy-Hb measurement of R-DLPFC. M: Relationship between the accuracy of the 2-back task and the Oxy-Hb values of the R-FPA.

task to task.

3.4. Relationship between brain activation and behavior performance

Pearson's correlation analysis was performed to inspect the relationship between EF task performance and the Oxy-Hb data. We discovered that Oxy-Hb measurement in R-DLPFC was negatively correlated with shifting cost accuracy in the dots–triangles task ($r = -0.427$, $p = 0.011$, FDR corrected $p = 0.08 > 0.05$, Fig. 4L). The Oxy-Hb measurement in R-FPA in the 2-back task had a slightly negative correlation with accuracy ($r = -0.349$, $p = 0.034$, FDR corrected $p = 0.21 > 0.05$, Fig. 4M).

4. Discussion

4.1. Effect of UNS soccer training on improving cognitive flexibility in ID adolescents and its brain mechanisms

In the dots–triangles task, the soccer group had better accuracy performance than the control group, which indicated that the cognitive flexibility of the soccer group was better than the control group. The result is consistent with previous studies.[56] Hotelling's T2 tests suggested that marginal significant differences between the two groups in the activation of the six ROI in the prefrontal cortex during the dots–triangles task. According to the non-FDR-corrected p value, R-DLPFC activation decreased in both groups, and the soccer group had higher activation of R-DLPFC Oxy-Hb than the control group. The possible reasons are discussed below. First, previous studies suggest that the DLPFC is involved in cognitive flexibility.[39] DLPFC activation increases in response to shifting rules or set changes during a task.[57,58] Therefore, the decrease in R-DLPFC activation in both groups may be related to cognitive flexibility dysfunction in ID people. Second, both groups showed reduced R-DLPFC activation during the dots–triangles task, which could have been associated with their low IQ. Parieto-frontal integration theory suggests that the main IQ-related brain regions are located in the DLPFC and inferior parietal lobe.[59] Reduced activation of the R-DLPFC in both groups might have indicated damage to this region, possibly related to lower IQ in the two groups.

There are two possible reasons for the higher activation of Oxy-Hb in the R-DLPFC of the soccer group than in the control group. First, it could have been related to the difficulty of task.[60] DLPFC activation is often associated with overall task difficulty, this region was more involved in the least difficult shifting condition.[61] Additionally, according to the compensatory utilization of neural circuits hypothesis, when completing simple tasks, the soccer group needed to recruit more neural resources to compensate for decreased cognitive efficacy, resulting in increased brain activation in the soccer group.[60] The higher accuracy indicated that the soccer group completed the dots–triangles task more easily, suggesting that the soccer group had better cognitive flexibility than the control group. Second, FDR-corrected p-value for Pearson correlation is marginally significant, there may be a moderate correlation between the subject's behavioral performance and brain activation during the task. Pearson's correlation analysis showed that the higher the R-DLPFC activation, the lower the shifting cost accuracy, indicating better cognitive flexibility, which means the soccer group had better cognitive flexibility than the control group, and exercise may alter brain activation, improving cognitive flexibility.[62] Many studies have demonstrated that exercise and long-term exercise can activate the DLPFC.[63–65] The behavioral performance result suggests that UNS soccer training may positively affect cognitive flexibility in adolescents with ID. However, the FDR-corrected p-value was not significant, it is unclear whether soccer training may improve activation of R-DLPFC.

4.2. Effect of UNS soccer training on improving working memory in ID adolescents and its brain mechanisms

In the 2-back task, the soccer group had higher accuracy than the control group. This higher accuracy indicated better task performance, suggesting that the soccer group had better working memory performance than the control group. It is consistent with previous studies showing that long-term exercise improves ID adolescents' working memory.[48,66] Hotelling's T2 tests confirmed significant differences between the two groups in the activation of the six ROI in the prefrontal cortex during the 2-back task. R-FPA activation was significantly lower in the soccer group than in the control group, indicating that the soccer group had better working memory. However, there were no significant differences in correlations between behavior and FPA brain activation in the 2-back task according to FDR correction. Thus, there is a need of a cautious interpretation of the results. According to the non-FDR-corrected p value, R-VLPFC activation was lower in the soccer group than in the control group. Previous studies have confirmed that the 2-back task activates FPA and VLPFC,[40,41] and that VLPFC plays an essential role in working memory.[42] The soccer group had lower R-FPA and R-VLPFC activation than the control group. Long-term exercise may reduce prefrontal hemodynamic responses during working memory tasks,[67] indicating that exercise can improve working memory.[68] According to neural efficacy theory, the better an individual performs on a task, the fewer the neural networks or nerve cells needed to complete the job, the lower the glucose consumption, and the higher the neural efficacy.[69,70] In the 2-back task, the soccer group had lower activity in the R-FPA and R-VLPFC than the control group, indicating that the soccer group needed fewer resources to perform the task, and 2-back was simpler for the soccer group.

Moreover, long-term exercise promotes task-efficient cerebral oxygenation and improves oxygen utilization during cortical activation.[71] Therefore, the soccer group had lower Oxy-Hb activation than the control group. In addition, the correlation between behavior and brain activation in the 2-back task showed that the higher the accuracy, the lower Oxy-Hb activation in the R-FPA. The soccer group had higher accuracy than the control group in the 2-back task, and R-FPA activation was lower than in the control group, indicating that the soccer group had better cognitive flexibility. However, R-VLPFC had no relationship with accuracy in the 2-back task, possibly because activation of the ventral prefrontal region was related to the working memory load. With increased memory load, reaction time increases and accuracy decreases, and ventrolateral PFC activation decreases during encoding.[72] Less R-VLPFC activation in the soccer group indicated less memory load during the task, confirming that the soccer group had better working memory than the control group. However, during the 2-back task, p-values after the FDR adjustment did not reach statistical significance ($p < 0.05$) in R-VLPFC activation. Therefore, UNS soccer training may positively affect working memory in adolescents with intellectual disabilities by improving activation of RFA, but whether it activates R-VLPFC is uncertain.

4.3. Effects of UNS soccer training on inhibitory control in ID adolescents

In the flanking task, neither the behavioral results nor the fNIRS results were significantly different between the two groups, although the soccer group generally had higher accuracy than the control group. This finding is inconsistent with previous research showing that chronic exercise intervention has beneficial effects on inhibitory control in individuals with autism,[34] attention-deficit hyperactivity disorder,[73] and developmental coordination disorder.[74] However, the effects of long-term exercise on executive function are influenced by factors such as exercise type, length, intensity of intervention, duration of the sessions, sample age, and evaluation tasks.[75] Therefore, few articles are studying inhibitory control in adolescents, no reports on adolescents with intellectual disabilities, and only a few studies using flanker tasks, which may be the reason for the inconsistent results. In addition, considering group compliance, our use of a different flanker task from previous literature may be one of the reasons for the different results. What's more, the soccer group in this study was mainly involved in soccer training, and different exercise methods could account for the inconsistencies with previous findings. However, despite the high number of studies that reported positive outcomes, a meta-analysis shows that of 10 studies that met the inclusion criteria, five studies affirmed the benefits of inhibitory control after the chronic exercise intervention proposed, and five did not show such amelioration, indicating that the previous meta-analysis's inclusion criteria were less stringent, affecting the findings.[76] Moreover, evidence for the behavioral and brain mechanisms underlying the effects of chronic exercise on inhibitory control in adolescents with intellectual disabilities is lacking. Previous study shows that acute exercise of varying intensities has no effect on brain activation during the flanker task.[77] But there is more evidence about the effects of acute exercise on inhibitory control but less evidence about the effects of UNS football training on inhibitory control, and less evidence about brain mechanisms may also be responsible for the different results. Furthermore, our sample size was small, and given inter-individual differences, it is challenging to expect different participants to obtain the same benefits from the exercise intervention.[78,79] The specific reasons should be further investigated.

4.4. Limitations

This study has a few limitations that should be considered. Firstly, we must clarify that this study is not a physical activity intervention study and has a small sample size. Therefore, further research using intervention designs and larger sample sizes would provide more conclusive evidence regarding the causal relationship between the Special Olympics UNS soccer training program and improvements in executive function.

Secondly, fNIRS systems have many advantages in cases where participant safety and comfort is a priority, and there are no safety concerns and fNIRS can be used with all participants from premature infants[80] to patient populations. However, fNIRS as a neuroimaging technique has limitations. While fNIRS allows for non-invasive assessment of cerebral blood oxygen concentration changes, it is limited to detecting activity within approximately 2–3 cm of the cortical surface. Future studies employing other neuroimaging techniques, such as functional magnetic resonance imaging (fMRI), could provide a more comprehensive understanding of the neural mechanisms involved.

Lastly, this study focused solely on the effects of the UNS soccer training program on executive function in adolescents with ID, without considering other factors that may influence executive function. Due to various reasons such as the epidemic, we are unable to conduct a randomized controlled study. Therefore, this study mainly compares the differences in executive function behavioral performance and brain activation of adolescents with intellectual disabilities in the UNS soccer group and the control group. No information is given about the brain activity after exercise, which is also a shortcoming of this study. Future studies could investigate the interplay between cognitive abilities, environmental factors, and individual characteristics to provide a more comprehensive understanding.

Despite these limitations, this study provides valuable insights into the potential benefits of the Special Olympics UNS soccer training program for executive function in adolescents with ID. Further research addressing these limitations would enhance our understanding and inform future interventions and programs to improve executive function in this population.

5. Conclusions

The findings of this study demonstrate that UNS soccer training may potentially modulate the activation patterns of the right frontoparietal area (R-FPA), leading to improvements in working memory in adolescents with ID. Furthermore, the behavioral performance results suggested that UNS soccer training may positively affect cognitive flexibility in adolescents with ID. However, it is unclear whether soccer training may improve activation of R-DLPFC. We need to interpret these results more cautiously. No significant differences were observed in inhibitory control between the UNS soccer training group and the control group. These results indicate that the UNS soccer training program holds promise for enhancing executive function in adolescents with ID, offering valuable insights into the potential cognitive benefits of this program and its significance for improving the quality of life in this population. However, excessive volumes of intense soccer training predispose some players to overload injuries. We should arrange exercise load and intensity reasonably to reduce the risk of injury.

Declaration of competing interest

The authors report no declarations of interest.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jesf.2023.12.006.

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