Children’s cognitive function and mental health based on finite element nonlinear mathematical model

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Abstract

This article uses a finite element nonlinear mathematical model to analyse the psychological conditions of children with certain physical defects. The thesis uses exercise and psychological intervention to intervene in children with material defects and scores the children’s mental state and cognitive status after the intervention. After our training and psychological intervention, the study found that the psychological evaluation scores of children with physical defects increased significantly. Before and after the intervention, there are apparent differences in children’s cognition in vocabulary and arithmetic. There is a nonlinear negative correlation between children’s cognitive abilities with physical defects and the scores of mental health status and neuropsychological evaluation. For this reason, the study concluded that movement and psychological intervention play a significant role in improving the cognitive function of children with physical defects.

Keywords: finite element, nonlinear mathematics, children’s cognitive function, children’s mental health

AMS 2010 codes: 34A34

1 Introduction

Obesity is a condition of physical defects in young children. Obesity has become one of the problems that threaten human health. The rapid increase in obesity in children and adolescents indicates a substantial hidden health risk. Nonlinear mathematical equations are fundamental equations that often appear in many physical problems such as gas diffusion and heat conduction [1]. In many cases, it is difficult to obtain exact
solutions to nonlinear mathematical equations. Due to the needs of actual calculations, different finite element grids are sometimes used for spatial regions at other times. Some scholars have proposed a moving mesh finite element method for solving the initial-boundary value problem of parabolic equations. It has been widely used to study some equations, such as linear hyperbolic equations, parabolic equations, parabolic integrodifferential equations, and nonlinear parabolic problems and hyperbolic problems. However, these documents are all aimed at coordinating elements. A few scholars have carried out non-conforming finite element analysis of the variable mesh format for linear hyperbolic problems and viscoelastic problems and gave corresponding error estimates. Finite element nonlinear mathematics has done a little research on psychology [2]. Based on this research background, this study is based on finite element nonlinear mathematics to study the relationship between the mental health status and cognitive function of obese children. On this basis, this study explores the impact of an exercise intervention on the mental health status and cognitive part of obese children.

2 Objects and methods

2.1 Research object

The paper selects obese children from the 2019 weight loss summer camp as the research object. We screened all the subjects for overweight and obesity according to the ‘Classification Standard for Body Mass Index Values for Overweight and Obesity Screening in Chinese School-age Children and Adolescents.’ After introducing the purpose and content of this study to the trainees, based on the principle of informed consent of all trainees, we strictly followed the inclusion criteria to select 11 children (8 males and 3 females) who were willing to participate. Simultaneously, we decided on 11 healthy control children (8 males and 3 females) matching normal body fat, age, height, sex, and education level according to the 1:1 matching principle. The subjects of the study are all right-handed [3]. All study subjects had no mental or neurological disorders, family history, brain trauma, brain surgery history, no hypertension, or diabetes. The basic situation is shown in Table 1.

| Group          | N  | Age (years) | Weight (kg)   | BMI (kg/m²) |
|----------------|----|-------------|---------------|-------------|
| Obesity group  | 11 | 12.24 ± 1.08| 63.12 ± 10.62| 30.26 ± 8.52|
| Control group  | 11 | 11.67 ± 1.23| 39.98 ± 6.26 | 17.47 ± 7.48|

2.2 Method

2.2.1 Determination of physical indicators

The examinee was measured by a dedicated person in terms of height (cm) and weight (kg) and the BMI value (kg/m²) was calculated. The waist circumference (WC) and hip circumference (HC) were measured with a soft ruler with a millimetre scale. Each index was measured thrice and then the average value was taken. We calculated the waist-to-hip ratio (WHR) after the reading accurate up to two decimal places [4].

2.2.2 Mental health assessment

We used the Mental Health Scale for School-age Children in China to evaluate 60 items of the mental health of obese children. According to the factor score value of 10 factors, after filling out the scale, we can preliminarily judge which factors comprise mental health problems.

In addition to judging by the scores of 10 factors, we can also use the total average score for an overall evaluation: the total average mental health score = the sum of the scores of 60 items/60.

We used the total average score to evaluate the mental health of middle-school students: 2–2.99 points
indicate that there are mild mental health problems. A score of 3–3.99 indicates that there is a moderate mental health problem [5]. A score of 4–4.99 indicates that there is a severe mental health problem.

### 2.2.3 Cognitive function assessment

We applied the revised Chinese Webster’s Intelligence Scale for Children to assess the neuropsychological characteristics of obese children. The test includes 11 subtests divided into two subscales, namely the speech subscale and the functional subscale. The speech scale consists of six factors: knowledge, classification, arithmetic, vocabulary, comprehension and memorization; the functional subscale includes five elements of drawing, picture arrangement, building block diagram, puzzle and coding. Neural assessments are completed by specially trained personnel [6]. The test environment needs to be naturally quiet. Implied answers cannot be given during the test, and the test is required to be completed at one time within 50–70 min.

### 2.2.4 Aerobic exercise intervention programme

The first part is warm-up exercises (mainly games). The second part is skipping + standing ups + cycling exercises (30 m running at medium speed + 15 m jogging + 30 m running sideways + 20 m fast running + 30 m backwards + 10 vertical jumps + 30 m sprinting). The third part is kickboxing (volunteers monitor their heart rate. We ask for part of the heart rate to be 100 beats/min, and the basic part of the heart rate is 140 beats/min to 160 beats/min). The activity frequency is 5 days/week, two times/days, two hours/time and rests for 30 min every 2 h. The exercise intensity reaches 70–80% of my heart rate. We use a heart rate telemeter to monitor the radial artery pulse with an artificial touch [7]. We require that the heart rate of the preparation part of the exercise is about 100 beats/min and the heart rate of the basic part is 140–160 beats/min.

### 2.3 Smagorinsky model with nonlinear slip boundary conditions

We stipulate that the Smagorinsky model is

\[-\mu \Delta u + (u \cdot \nabla)u - \nabla \cdot ((C \cdot \alpha)^2 |\nabla u| \nabla u) + \nabla p = f\]

where \(\Omega \in \mathbb{R}^2\) is a bounded convex domain, \(C_i\) is a constant and \(\delta\) is a spatial function. \(g\delta\) is the radius \(|\sigma| := \sqrt{\sum_{i,j=1}^{d} |\sigma_{ij}|^2}\) in the LES system. This paper considers the following nonlinear slip boundary conditions:

\[
\begin{align*}
    u &= 0 \\
    u_n &= u \cdot n = 0, \quad \sigma_t(u) \in g\delta |u|_\tau
\end{align*}
\]

where \(\Gamma \cap S = \emptyset, \Gamma \cap S = \partial \Omega\). \(g(x)\) is a scalar function and satisfies \(g > 0\) which represents the unit vector on s.

\(u\), \(\sigma_t(u)\) represents the tangential component of the velocity and the tangential component of the stress vector, where the stress vector can be described as \(\sigma = \sigma(u, p) = (ue_{ij}(u) - p \delta_{ij})n_j, e_{ij}(u) = \frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}, i, j = 1, 2\) which is the deformation velocity tensor. Definition of subdifferential \(\partial \psi(a)\): if \(\psi\) is a weak lower semicontinuous functional, then \(\partial \psi(a)\) is defined as the subdifferential set of \(\psi\) at \(a \in L^2(S)\): \(\partial \psi(a) = \{b \in L^2(S) : \psi(h) - \psi(a) \geq b(h - a), \forall h \in L^2(S)\}\). This article uses the following symbols and spaces:

\(L^p(\Omega)\) represents an unusual Lebesgue space, and its norm is:

\[|\psi|^p := \left(\int_\Omega |\psi|^p dx \right)^{1/p}\]

\(W^{m,p}(\Omega)\) represents a remarkable Sobolev space, and its example is:

\[
\begin{align*}
    V &= \{u \in H^1(\Omega)^2, u|_{\Gamma} = 0, un|_{s} = 0\}, V_0 = H_0^1(\Omega)^2 \\
    V_p &= \{u \in V, \text{div} u = 0\}, M = L^2(\Omega) = \{q \in L^2(\Omega), \int_{\Omega} q dx = 0\} \\
    V_3 &= W^{1,3}(\Omega)^2 \cap V, V_{3\sigma} = \{u \in V_3, \text{div} u = 0\}
\end{align*}
\]
The standard in space $F$ is defined as:

$$\|v\|_F = (\int_{\Omega} |\nabla v|^2 \, dx)^{\frac{1}{2}}, \forall v \in V$$

(5)

Defining the trilinear structure in space as $V \times V \times V$:

$$b(u,v,w) = ((u \cdot \nabla)v, w) + \frac{1}{2}((\text{div}u)v, w) = \frac{1}{2}((u \cdot \nabla)v, w) - \frac{1}{2}((u \nabla)w, v)$$

(6)

$$\forall u, v, w, \in V$$

Then the variational form of formulas (1) and (2) is as follows: find $(u, p) \in V \times M$ so that for all $(v, q) \in V \times M$ is:

$$\begin{cases}
    a(u, v - u) + b(u, v - u) + (C_s \delta)^2(|\nabla u|\nabla v - \nabla u) + j(v_\tau) - j(u_\tau) - d(v - u, p) \geq (f, v - u) \\
    d(u, q) = 0
\end{cases}$$

(7)

Of them, $j(v_\tau) = \int_\gamma g|v_\tau|\,ds$. Saito proves in the literature that $d(\bullet, \bullet)$ satisfies the inf – sup condition on $V \times M$, that is, there is a constant $\beta_0 > 0$ such that:

$$\beta_0 \|q\| \leq \sup_{v \in V} \frac{d(v, q)}{\|v\|_V}$$

(8)

### 2.4 Finite element approximation

We use $T_h$ to denote the division of a cluster of quasi-consistent triangles on $\Omega$, and the corresponding triangle sequences are, respectively, indicated as $K_1, K_2, \ldots, K_n$ and $h_i$ represents the diameter of $K_i, i = 1, \ldots, n$ and $h = \max \{h_1, h_2, \ldots, h_n\}$. $P_r(K)$ is a polynomial of degree no more than $r$ defined on $K \in T_h$. Introducing the subspace of finite element $V$ and $M$:

$$W_h = \{v_h \in C(\overline{\Omega})^2, v_h|K \in P_2(K)^2, \forall K \in T_h\}$$

(9)

$$V_h = W_h \cap V, V_{0h} = W_h \cap V_0, V_{3h} = W_h \cap V$$

$$M_h = \{q_h \in C(\overline{\Omega})^r, q_h|K \in P_1(K), \forall K \in T_h\} \cap M$$

### 2.5 Statistical processing

We use the SPSS13.0 statistical software package to enter the data, and the results are expressed as quantitative data between and within groups using independent sample $T$-test and paired $t$-test, respectively, and Pearson correlation analysis [8]. $P < 0.05$ was considered as statistically significant.

**Table 2** Comparison of general clinical data of obese children after aerobic exercise intervention

| Group | After the intervention | Before intervention | Control group |
|-------|------------------------|---------------------|---------------|
| WC (cm) | 55.48 ± 5.79 | 92.19 ± 8.45 | 56.12 ± 4.57 |
| HC (cm) | 66.11 ± 5.85 | 100.02 ± 4.18 | 66.39 ± 5.36 |
| WHR | 0.84 ± 0.06 | 0.92 ± 0.05 | 0.85 ± 0.02 |
| BMI | 18.25 ± 2.57 | 30.26 ± 8.52 | 17.47 ± 7.48 |

HC, hip circumference; WC, waist circumference; WHR, waist-to-hip ratio.
3 Results

3.1 Comparison of general clinical data of obese children after aerobic exercise intervention

Compared with the control group, the WC, HC, and WHR of obese children were significantly higher (P < 0.01), and the difference was very significant. Fasting blood glucose and insulin resistance index increased significantly (P < 0.05), which was substantial (Table 2) [9].

3.2 Comparison of the mental health status of obese children after aerobic exercise intervention

We conducted an overall assessment of the scores of the various factors of the mental health scale for children of different weights, as shown in Table 3.

Table 3 Comparison of the scores of various factors of the mental health scale for obese children after aerobic exercise intervention.

| Test items          | Symptom          | Paranoid | Hostility       | Interpersonal relationship | Depression       |
|---------------------|------------------|----------|----------------|---------------------------|------------------|
| p                   | 0.043            | 0.044    | 0.006          | 0                         | 0.003            |
| t                   | 2.655            | 2.961    | 3.751          | 6.695                     | 4.734            |
| Score after intervention | 1.94 ± 0.42 | 1.25 ± 0.14 | 1.97 ± 0.62 | 2.03 ± 0.31 | 2.44 ± 0.68 |
| p                   | 0.043            | 0.035    | 0.049          | 0                         | 0                |
| t                   | 2.608            | 2.89     | 2.281          | 16.227                    | 0.003            |
| Pre-intervention score | 3.65 ± 0.92 | 3.43 ± 1.04 | 3.16 ± 0.43 | 4.95 ± 0.51 | 2.44 ± 0.68 |
| Control score       | 1.71 ± 0.51      | 0.93 ± 0.33 | 1.18 ± 0.40 | 1.04 ± 0.38 | 1.26 ± 0.47 |
| Test items          | Anxiety          | Study-induced stress | Maladaptation | Emotional imbalance | Total score |
| p                   | 0                | 0.049    | 0.049          | 0                         | 0.001            |
| t                   | 8.95             | 2.209    | 2.256          | 2.365                     | 5.047            |
| Score after intervention | 2.76 ± 0.49 | 1.92 ± 0.44 | 2.06 ± 0.25 | 2.35 ± 0.33 | 2.11 ± 0.52 |
| p                   | 0.001            | 0.046    | 0              | 0                         | 0                |
| t                   | 5.323            | 2.793    | 7.997          | 6.1                       | 6.803            |
| Pre-intervention score | 4.87 ± 1.22 | 3.18 ± 1.01 | 4.15 ± 0.83 | 4.48 ± 1.11 | 4.05 ± 0.79 |
| Control score       | 1.07 ± 0.39      | 1.87 ± 0.66 | 0.45 ± 0.12 | 0.78 ± 0.15       | 1.13 ± 0.38       |

3.3 Comparison of cognitive function test scores of obese children after aerobic exercise intervention

Compared with the control group, obese children have lower scores in all items of neuropsychological tests. The five factors of vocabulary, arithmetic, back number, block diagram and number symbols are significantly reduced. The difference between the two is very significant (P < 0.01). The aerobic exercise intervention and the neuropsychological test of obese children all improved compared with before the intervention. The five factors of vocabulary, arithmetic, memorial number, block diagram and number symbols were significantly higher than before the intervention. The difference between the two is very significant at P < 0.01 [10].

3.4 Correlation analysis of obese children’s BMI and neuropsychological test scores

Obese children’s BMI is negatively correlated with the test scores of neuropsychological assessment items, vocabulary, arithmetic, back number, block diagram and number symbols ($r = -0.398$, $p = 0.011$; $r = -0.445$, $p = 0.043$; $r = -0.322$, $p = 0.043$; $r = -0.423$, $p = 0.003$; $r = -0.368$, $p = 0.003$). Figure 1 shows the correlation between BMI and neuropsychological test scores in obese children.
Table 4 Comparison of cognitive function test scores of obese children after aerobic exercise intervention.

| Test factor | Common sense | Similar | Vocabulary | Arithmetic | Understanding |
|-------------|--------------|---------|------------|------------|--------------|
| p           | 0.412        | 0.579   | 0.009      | 0.008      | 0.761        |
| t           | 0.855        | 0.573   | 3.394      | 3.461      | 0.312        |
| Score after intervention | 27.12 ± 4.90 | 15.20 ± 5.02 | 27.23 ± 4.75 | 15.17 ± 3.60 | 16.42 ± 2.18 |
| p           | 0.846        | 0.396   | 0.001      | 0.003      | 0.189        |
| t           | 0.199        | 0.885   | 5.803      | 4.14       | 1.408        |
| Pre-intervention score | 26.71 ± 4.75 | 13.60 ± 3.28 | 17.14 ± 3.27 | 9.79 ± 2.36 | 15.15 ± 2.05 |
| Control score | 28.80 ± 4.29 | 16.38 ± 4.63 | 30.16 ± 5.10 | 18.45 ± 6.51 | 16.87 ± 4.26 |
| Test factor | Back number | Picture fill | Picture arrangement | Wooden block diagram | Number sign |
| p           | 0.009        | 0.773   | 0.545      | 0.008      | 0.006        |
| t           | 3.193        | 0.296   | 0.625      | 3.257      | 3.831        |
| Score after intervention | 11.87 ± 2.95 | 23.65 ± 3.88 | 9.34 ± 1.78 | 8.46 ± 2.28 | 32.63 ± 4.87 |
| p           | 0.001        | 0.652   | 0.495      | 0.004      | 0        |
| t           | 5.395        | 0.464   | 0.707      | 4.566      | 6.817        |
| Pre-intervention score | 6.68 ± 1.22 | 22.95 ± 3.15 | 8.80 ± 1.80 | 4.88 ± 1.25 | 18.56 ± 4.81 |
| Control score | 13.63 ± 4.45 | 24.35 ± 6.81 | 10.12 ± 3.73 | 9.67 ± 2.23 | 36.00 ± 3.68 |

Fig. 1 The correlation between BMI and neuropsychological test scores in obese children.

3.5 Correlation analysis between the total scores of the mental health assessment scale for obese children and neuropsychological test scores

There was a positive correlation between the BMI of obese children and the total score of the Mental Health Assessment Scale for Obese Children ($r = 810.3366$, $pD = 303.0115$). The total score of the Mental Health Assessment Scale for Obese Children is negatively correlated with the test scores of neuropsychological assessment items, vocabulary, arithmetic, back number, wooden block diagram and number symbol ($r = -0.398$, $p =$
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Figure 2 shows the correlation between the total scores of the mental health assessment scale for obese children and the neuropsychological test scores.

![Graph showing correlation between mental health assessment and neuropsychological test scores.]

4 Discussion

Studies have shown that most obesity has psychological problems of varying degrees. The most obvious manifestations are frequent moodiness, excessive inferiority, lack of self-confidence and withdrawn personality. Children who weigh more than average are often seen as clumsy, backward and ridiculed because of their bloated stature. These ridicules make them feel inferior and mentally stressed, and the probability of depression, irritability and rebellious behaviour is higher than that of normal children. Obese children have severe emotional problems that lead to their bodies getting fatter and fatter. This may be because obese children have a lot of body fat, decreased brain nerve cell function, and reduced information transmission and slow thinking. The mental retardation of obese children affects learning efficiency and academic performance, and the psychological pressure is greater than the weight pressure. Obese children are rejected or ridiculed in group activities because of their inappropriate actions. This phenomenon seriously hurts the self-esteem of obese children. External prejudice and self-sensitivity make them unwilling to take the initiative to participate in collective activities, which directly leads to a decline in social interaction and adaptability. Long-term psychological problems such as depression, anxiety and poor interpersonal relationships are prone to occur.

A large number of studies have shown that obese children’s ability to concentrate is significantly decreased. Obesity harms children’s attention distribution, working memory load, hand coordination and understanding of problems. Obesity interferes with the ability of the brain to work and reduces the quality of the brain’s work. Compared with normal-weight children, obese children have more deficient coordination of psychological movements, and their reaction speed, ability to grasp the main points, perception and acceptance are significantly reduced [11]. The results of the study suggest that obesity harms children’s cognitive function. This study found that the scores of all items in the neuropsychological test of obese children were significantly reduced. The scores of five vocabulary factors, arithmetic, back number, wooden block diagram and number symbols were substantially lower than those of the standard control group. The results show that obese children’s reasoning ability, attention ability, motor coordination ability, learning and memory ability, and organisational ability are all reduced, indicating that obesity has a particularly negative impact on children’s cognitive ability.

Compared with the control group, patients with generalised anxiety have the proper hippocampal nerve integrity, and the plasticity marker nitrogen-acetyl aspartate (NAA) and choline complex (Cho) concentrations are significantly reduced. The Penn State University Anxiety Questionnaire (PSWQ) score was significantly
negatively correlated with bilateral hippocampal NAA [12]. This study found a positive correlation between the BMI of obese children and the total score of the mental health assessment scale for obese children. The total score of the Mental Health Assessment Scale for Obese Children is negatively correlated with the test scores of neuropsychological assessment items, vocabulary, arithmetic, back number, wooden block diagram and number symbols. The results of the study show that the mental health of obese children harms their cognitive function.

Studies have shown that people’s regular participation in physical activities can eliminate mood disorders, slow down and treat certain mental illnesses, such as depression, and keep people in a positive mental state. Exercise can promote good interpersonal relationships, harmonious relationships, solidarity, and cooperation and help mental health. Movement can also make oneself establish a good self-concept and maintain a healthy attitude. According to another study, after training, the anxiety, depression and nervousness of the test subjects were significantly reduced, and the degree of happiness was increased considerably. Studies have found that aerobic exercise and strength and flexibility exercises can improve the mental health of exercisers. Both aerobic exercise and anaerobic exercise can reduce depression in depressed patients [13]. Besides, studies have found that appropriate long-term exercise can reduce the frequency of apolipoprotein E4 alleles in obese rats, thereby reducing the toxic effect of amyloid peptides on neuronal cell bodies and neurite outgrowth. Exercise can also reduce neuronal calcium ion levels, enhance neuronal membrane fluidity, and improve neuronal function and plasticity. Long-term aerobic exercise can increase cerebral blood oxygen saturation, improve blood circulation, and provide sufficient nutrition and oxygen supply for neurons. People’s long-term participation in aerobic exercise can increase the expression and utilisation of brain-derived neurotrophic factor and their receptors in the brain and change the morphology and structure of central neurons. Exercise can also increase the activity of the metabolic regulatory molecule PGC-1α in the muscles of obese people. This molecule stimulates the increase in the expression of FNDC5, which can promote the accumulation of proteins related to brain health to maintain the healthy growth of neurons and synapses.

This study found that after aerobic exercise intervention, both the scores of the various factors and the overall scores of the obese children’s mental health status scale were significantly reduced. The scores of different items in neuropsychological assessment, especially the five factors of vocabulary, arithmetic, back number, block diagram and number symbols, have significantly increased. Research results show that aerobic exercise has a positive effect on promoting the mental health of obesity and improving the cognitive function of obese children.

5 Conclusion

Through finite element nonlinear mathematical analysis, it is found that individual overweight has a non-linear negative correlation effect on children’s mental health and cognitive function. Exercise has significant practical value in promoting the mental health and cognitive function of obese children.

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