Detecting Problem Behavior in Children from Biological Signals: Validation through Chaos Analysis

Junko Tsujino, Mayumi Oyama-Higa, Member, IEEE and Mitsuko Tanabiki

Abstract — The relationship between biological signals and problem behavior in children was examined in a total of 87 children from a class of two-year-olds and a class of three-year-olds, with input from their mothers. The mothers were asked to fill out a checklist on the behavior of their children. Fingertip pulse waves were measured for use as biological data. The measured values were subjected to chaos analysis and the Lyapunov exponents calculated. The two-year-olds and the three-year-olds differed in the scores for “Withdrawn” and “Developmental Abnormality” as assessed by the criteria used in the behavior checklist. The two classes also differed significantly in their Lyapunov exponents. Among the two-year-olds, the Lyapunov exponent differed significantly between those who were withdrawn and those who were not. Among the three-year-olds, there was a significant difference in the Lyapunov exponent between children with severe attention problems and those with only minor attention problems. The Lyapunov exponent calculated by chaos analysis of fingertip pulse wave data appeared to be an effective index for scientifically studying problem behavior in young children.

INTRODUCTION

Difficulties in early childhood can frequently be aggravated, becoming fundamental causes of problems later in childhood and adolescence. Some studies have attempted to prospectively investigate the origins of problematic behavioral trends. It reported that as many as 61% of children who had shown hyperactivity, attention deficit, and aggressiveness when they were three years old were found to have similar problems at age eight when evaluated clinically. In boys studied at age two and followed up at age four, more than 40% showed persistence of problem behavior [1], [2].

These findings suggest that problem behavior is likely to originate in the early stages of child development. Problem behavior often develops along with the growth of the child and leads to various kinds of maladjustment at later stages of development. Therefore, it is important to intervene and treat the child as early as possible.

It conducted systematic studies on the classification and evaluation criteria of problem behavior in children and reported that such behavior could be divided into two broadband syndromes: “Internalizing,” which mainly consists of Anxious/Depressed” and “Withdrawn” states, and “Externalizing,” which mainly consists of “Aggressive and Destructive Behavior.” Thus, problem behavior in children can be assessed from internal and external viewpoints and from the perspective of the emotions associated with specific behaviors [3].

Problem behavior in children is thought to develop through the complex interplay of various factors, including genetic makeup and personality type of the child, personalities of the parents, and the rearing environment. Earlier studies clearly showed that among these, factors relating to the child’s home environment had a major effect. Maladjustment and manifestation of problem behavior in children seems to develop as a result of the interaction between several factors over time [4], [5], [6].

Therefore, intervention and treatment are best provided at as early a stage as possible. If corrective measures are taken early, then parents and children can be spared from further problems occurring in later childhood and adolescence. However, problem behavior in very young children, which is often thought of as transient, can sometimes be internalized within the child. Because of this, it is not always easy for parents and other adults around the child to understand the real nature of the problem. This leads to practical difficulties in understanding what is occurring within the child and between the child and his/her parents.

The objective of the present study was to find a method of detecting problem behavior in children from biological signals, in order to facilitate early prevention and countermeasures. In assessing problem behavior, we have given great weight to the specifics of behavior (core syndromes). We used fingertip pulse waves as biological data, which was then subjected to chaos analysis prior to calculating the Lyapunov exponents [3].

Chaos is different from randomness. Methods of differentiating randomness from chaos are well established and it has been demonstrated that pulse waves have chaotic characteristics. Humans send out chaotic waves as biological information. It has been experimentally clarified that a living body cannot be maintained if the cardiac waves are absolutely regular and not chaotic. Fingertip pulse waves are naturally synchronous with cardiac waves, but the two are not identical. The pulse waves are considered to be an output from multiple information networks of the living body.

METHOD

A. Study subjects

Thirty-two children (19 boys and 13 girls) from a class of two-year-olds and 55 children (28 boys and 27 girls) from a class of three-year-olds, totaling 87 children, took part in the study. Their mothers, who ranged in age from 21 to 45 years,
also participated by filling in a checklist. The children’s pulse wave measurements were obtained with their parent/guardians’ informed consent.

B. Location of the study
The experiment was conducted at two private nursery schools.

C. Study period
The study was conducted in September 2004 and from January to March 2005.

D. Measurement details and methods
(1) Measurement of the children’s fingertip pulse waves
The pulse waves were measured using a photoplethysmography sensor (CCI BC2000). The temperature of the room was about 25°C. The subjects were made to keep their eyes open while measurements were made through a cuff attached to the left index finger. The pulse waves were measured twice, for 1 minute each time.

(2) The mothers filled in the checklist on the children’s behavior.

The Japanese version CBCL/2–3 of the Child Behavior Checklist 2–3 was used for preparing the checklist. The original checklist contained six core syndromes, Anxious/Depressed, Withdrawn, Sleep Problems, Somatic Complaints, Aggressive Behavior, and Destructive Behavior, and two broadband syndromes, Internalizing and Externalizing [7].

After factorial analysis, the Japanese version has eight core syndromes: Separation Anxiety, Anxious/Neurotic, Withdrawn, Oppositional, Aggressive/Destructive, Attention Problems, Developmental Abnormality, and Sleep/Eating Problems, and the same Internalizing and Externalizing broadband syndromes as in the original checklist [8], [9].

The distribution of the checklist items among the core syndromes was as follows.
1) Separation Anxiety: 7 items: 3, 10, 11, 37, 68, 73, and 92
2) Anxious/Neurotic: 11 items: 33, 46, 47, 48, 50, 54, 63, 84, 87, 91, and 99
4) Oppositional: 16 items: 8, 13, 15, 16, 20, 21, 29, 30, 44, 66, 81, 82, 83, 85, 96, and 97
5) Aggressive/Destructive: 12 items: 9, 17, 18, 27, 34, 35, 40, 42, 49, 53, 58, and 72
6) Attention Problems: 4 items: 5, 6, 36, and 59
7) Developmental Abnormality: 6 items: 2, 31, 56, 76, 77, and 80
8) Sleep/Eating Problems: 8 items: 22, 24, 38, 61, 64, 65, 74, and 94

The contents of each item, the methods of assessment, and the method of scoring used were the same as in the original version.

The mothers were asked to record their names on the checklists of their children’s behavior so that the children could be traced to their mothers. Each instance when the fingertip pulse wave data of the child and the checklist filled by the child’s mother were both available was taken as one case.

RESULTS

A. Mean age of the children
The mean ages of the children were:
Class of two-year-olds: three years and three months (SD: 4.5 months)
Class of three-year-olds: four years and two months (SD: 4.3 months)

B. Mean values and SD of the scores for each core syndrome in two-year-olds and three-year-olds and the result of testing for significant differences

CBCL/2-3 core syndrome scores for the two-year-old class and the three-year-old class were tested for significant differences. The results showed that the three-year-olds had higher scores for Developmental Abnormality (t=2.331, p<0.05) and Withdrawn (t=1.737, p<0.1) categories. Table 1 shows the mean values and SD of the scores for each core syndrome of the two classes and the results of testing for significant differences.

<table>
<thead>
<tr>
<th>TABLE 1</th>
<th>Mean values and SD of the scores for each core syndrome within the two classes and the results of testing for significant differences</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
</tr>
<tr>
<td>Separation Anxiety</td>
<td>3.41</td>
</tr>
<tr>
<td>Anxious/Neurotic</td>
<td>1.50</td>
</tr>
<tr>
<td>Withdrawn</td>
<td>2.18</td>
</tr>
<tr>
<td>Oppositional</td>
<td>0.81</td>
</tr>
<tr>
<td>Attention Problems</td>
<td>1.45</td>
</tr>
<tr>
<td>Developmental Abnormality</td>
<td>2.91</td>
</tr>
<tr>
<td>Sleep/Eating Problems</td>
<td>2.41</td>
</tr>
<tr>
<td></td>
<td>2.64</td>
</tr>
</tbody>
</table>
TABLE 2 shows the means and standard deviations of the Lyapunov exponents from both classes.

<table>
<thead>
<tr>
<th>Class</th>
<th>Mean</th>
<th>Standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Two-year-olds</td>
<td>4.089</td>
<td>1.448</td>
</tr>
<tr>
<td>Three-year-olds</td>
<td>3.308</td>
<td>0.866</td>
</tr>
</tbody>
</table>

D. Relationship between the CBCL/2-3 core syndrome scores and the Lyapunov exponent

The two-year-olds showed a significant difference in the Lyapunov exponent between those with high and low scores in the Withdrawn category (t=2.75, p<0.01). The children with a high score in the Withdrawn category had a low Lyapunov exponent and those with a low score had a high Lyapunov exponent.

Among the three-year-olds, there was a significant difference in the Lyapunov exponent between those with high and low scores for Attention Problems (t=1.67, p<0.1). The children with a high score for Attention Problems had a low Lyapunov exponent and those with a low score had a high Lyapunov exponent.
DISCUSSION

This paper examined the potential usefulness of the Lyapunov exponent for detecting problem behavior in young children from biological signals. From birth, children's development is rapid, both mentally and physically. The children covered in this study had a mean age of three years and three months in the “two-year-old” class and of four years and two months in the “three-year-old” class. It is likely that behavioral problems would change during this early phase of childhood, when growth is very fast.

By about three years of age, children understand the permanence of relationships and can focus their attention on the outside world without becoming anxious. They start exploring the world around them without fear and become very self-assertive.

At around the age of four, they become aware of the fact that they cannot do everything that adults can and that there is much they do not know. It is said that if children feel accepted by those around them at this stage, they develop a realistic self-opinion and become capable of facing and overcoming difficulties later in childhood and during adolescence.

The scores for the different behaviors measured in this study showed a significant trend for the three-year-olds to have a higher score in the Withdrawing category than the two-year-olds. The three-year-olds also scored significantly higher in Developmental Abnormality. The Withdrawn core syndrome, which includes items like “Cannot get along with other children,” is an expression of willingness to interact realistically with peers, and it can be understood as an indication that the three-year-olds were becoming aware of interpersonal relationships. The three-year-olds were at a stage when individual differences between the children were more prominent than they were between the two-year-olds and the Developmental Abnormality syndrome that included items like “Immature for his/her age,” which reflected the evaluator’s (mother’s) impressions of the child’s behavior. It is believed that problem behavior becomes perceptible to people around children at about the three-year-old stage.

Significant differences were seen between the Lyapunov exponents of the two-year-olds and the three-year-olds. This is natural, considering that the children were at a stage of very rapid growth and knowledge acquisition. The Lyapunov exponent for the three-year-olds was significantly smaller than that for the two-year-olds, apparently because the three-year-olds had more self-awareness and their consciousness was more internalized than that of the two-year-olds.

In terms of the relationship between problem behavior and Lyapunov exponents, the two-year-olds showed a significant difference in their Lyapunov exponent, depending on whether or not they had Withdrawn behavior. Children with high score for Withdrawn behavior had smaller Lyapunov exponents, and therefore, lower levels of measurable biological activity than those with a zero score for Withdrawn behavior. Withdrawn is a core syndrome that identifies withdrawal behavior as an emotional response. However, the items under Withdrawn also included many symptoms associated with communication problems and autistic tendencies. Individuals with communication problems or autistic tendencies have a limited interest in others and the happenings around them.

Because of this, the biological data, which reflect the level of control over the environment, is expressed in the Lyapunov exponents.

Among the three-year-olds, there was a difference in the Lyapunov exponent between children with high and low Attention Problems scores. A high score for Attention Problems was associated with a low Lyapunov exponent, suggesting low levels of activity in the appropriate response centers of the body. Attention Problems is a core syndrome included in the Japanese version, and distinguishes certain features of the Destructive Behavior syndrome in the original checklist. This suggests that hyperkinesia and attention deficit are universally observed. Hyperkinesia and attention problems are often described as being opposite to Withdrawn behaviors, but both indicate disharmony between the individual and others around him/her. Therefore, the relationship between Attention Problems and Lyapunov exponents can be seen as a measure of the fragility of environmental control, and the same can be said for Withdrawn behavior.

Problem behavior in children never arises only from problem factors within the child. Many factors may be involved, in a time series. We should remember that the child coexists with his/her mother right from the embryonic stage, and the mother is the main caretaker after birth. It suggested that there might be a very high correlation between the interactive behavior of parents and the interactive behavior of young children. The influence of the mother is paramount. The foundations of child–parent relationships, which are established early, appear to persist throughout life. It is thus important to deal with problem behavior in very young children as soon as possible [10], [11].

In an effort to scientifically understand the relationship between problem behavior in children and their biological signals, I measured fingertip pulse waves of children and carried out chaos analysis of the measured data. I hope that the scientific analysis presented here will be helpful in preventing psycho-behavioral problems in children and enable adoption of early countermeasures.

We are truly grateful to the principals and staff of the Ai Nursery School and the Himeji Himawari Nursery School and the parents of the children for their cooperation in making the plethysmographic measurements.


