

High-Resolution Actigraphic Analysis of ADHD: A Wide Range of Movement Variability Observation in Three School Courses – A Pilot Study

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Objectives: This study was conducted to determine whether or not newly proposed high-resolution activity features could provide a superior analytic foundation compared to those commonly used to assess transitions in children's activities, under circumstances in which the types of courses attended exert different situational effects on activity levels. **Methods:** From 153 children at a local elementary school, 10 subjects with attention deficit hyperactivity disorder (ADHD) and 7 controls were recruited. Their activity data was collected using an actigraph while they attended school. Ratios of partitioned activity ranges (0.5-2.8 G) during the entire activity were extracted during three classes: art, mathematics, and native language (Korean). Extracted activity features for each participant were compared between the two groups of children (ADHD and control) using graphs and statistical analysis. **Results:** Activity distributions between ADHD and control groups for each class showed statistically significant differences spread through the entire range in art class compared to native language and mathematics classes. The ADHD group, but not the control group, experienced many significantly different intervals (> 50%) having low to very high activity acceleration regions during the art and languages courses. **Conclusions:** Class content appears to influence the activity patterns of ADHD children. Monitoring the actual magnitude and activity counts in a wide range of subjects could facilitate the examination of distributions or patterns of activities. Objective activity measurements made with an actigraph may be useful for monitoring changes in activities in children with ADHD in a timely manner.

Keywords: Actigraphy, Attention Deficit Disorder with Hyperactivity, Motor Activity, Schools, Activities of Daily Living

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1. Introduction

Attention-deficit hyperactivity disorder (ADHD) is one of the most common neurobehavioral disorder of childhood, and has been estimated to affect 3-9% of school-age children [1-3]. Children with ADHD exhibit significant levels of inattention, hyperactivity and impulsivity. They commonly experience difficulties in completing their schoolwork and also tend to under-achieve academically [4]. The signs of ADHD can vary over time and situations even in a single individual, and thus a single assessment made in one brief visit may not truly reflect a patient's general level of activity or impairment [5]. Fluctuations in the symptoms of ADHD may complicate

its diagnosis. Considering that unfamiliar environments or situations may mitigate or aggravate the symptoms of ADHD, it is important to consider environmental contexts in the observational research and diagnosis of children with ADHD [6-9].

Beyond teacher reports, direct observation of students in their classroom, as compared to laboratory or clinical interviews, is an important means of understanding the characteristics of ADHD [6]. It has been previously noted that a classroom situation with a high stimulation level (noise, visual distracters, and a large class size) was likely to elicit the primary characteristics of ADHD. Several studies have been previously conducted to monitor the activities of children with ADHD in naturalistic classroom environments. Antrop et al. [10] reported that minor differential effects of time of day and playtime exerted minor differential effects on the hyperactive behavior of children with ADHD as compared to that of control children, specifically with regard to noisiness and out-of-seat behavior. Lauth et al. [6] have monitored the classroom activities of children with ADHD via external observers. The children with ADHD's off-task and on-task behavior (such as regular lesson with interaction, regular lesson with minimal interaction, and non-instructional context) were compared, and showed that children with ADHD were more disruptive and inattentive than their counterparts.

Activity is a complicated data situation, which reflects continuous and multi-dimensional changes in body position. An actigraph is an electronic device which can simplify and quantify complex activity information into numerical values. The most profound merit of the actigraph is that it allows for a patient's activity information to be obtained in a natural setting for a prolonged and continuous period [5,11,12]. Several methods for the objective measurement of the activity levels of children with ADHD were previously developed using actigraphs [7,9,13-16]. Tsujii et al. [8] compared the mean activity of children with ADHD and controls, and reported a sizeable difference in the mean activity between the two groups during the afternoon in-seat class period. In another study, differences in the activity levels of the two groups were noted (average and standard deviation) during recess time; however, no difference between the groups was detected during the in-seat class period.

These previous studies, however, utilized only limited activity information, such as means of or variances in the entire activity. Preexisting actigraphs were used to assess subject's activities by generating counts or summaries of activity: these measures did not designate the actual 'amount' or degree of activity, but rather the mere 'frequency' of intervals

in which high levels of activity above a certain pre-defined threshold, and thus we have hypothesized that they could not provide the series of informative features necessary to determine distribution or patterns of a wide range of activities. Several previous studies have utilized activity levels with the amount (intensity) of activities [9,17]. However, they utilized the total summed intensity of activities, and could not provide information regarding the distribution, patterns, or variance of a broad range of activities. To address this issue, we introduce a new feature generation scheme using the mean and variance of activity ratios of mutually exclusive intervals from low-level to high-level (0.5-2.8 G) on the activity degrees extracted with actigraphs. Moreover, we also explore the effects of a variety of courses on the activity of children with and without ADHD. In service of this objective, based on the features of two clinically diagnosed groups (ADHD and non-ADHD), we conducted intra- and inter-group comparisons of three types of courses including art, language and math. The principal objective of this study was to determine whether or not the newly proposed high-resolution activity features could provide a superior analytic foundation than previous traditional ones for assessing the transitions of children's activities, whereas the types of course attended exert differing situational effects on children's activity level.

II. Methods

1. Participants and Clinical Assessment

At first, 153 children (78 boys and 75 girls; mean age, 7.4 ± 0.58 years; range, 6 to 9 years) were recruited from a local elementary school, in South Korea. Questionnaires were administered using the Korean version of the Child Behavior Checklist (K-CBCL) [18,19] and the ADHD Rating Scale-IV (K-ARS) [20,21] for parents and teachers, after obtaining signed informed consent with a full explanation of the procedures of the study. Generally, the cutoff for a high-risk group has been established at a T-score of 63 on the K-CBCL questions and a high score of the upper 10% on the K-ARS [21]. In this study, children who scored a T-score of more than 60 on the K-CBCL questions or who were in the upper 10% on the K-ARS test were selected as the high-risk group.

Children in the high-risk group were interviewed and clinically diagnosed via close examinations and in-depth interviews conducted by four experienced child psychiatrists. Each interview included the Korean Kiddie-Schedule for Affective Disorder and Schizophrenia-Present and Lifetime Version-Korean Version (K-SADS-PL-K) [22] and mentality tests. Additionally, subjects' Intelligence Quotients (IQ) were

also evaluated using a vocabulary test and a block design test included in the Korean-Wechsler intelligence scale for children: 3rd ed. [23]. All participants were drug-free and had no history of stimulant therapy, both when evaluated and during data collection. None of the subjects had an IQ of less than 80. Hence, none of the participants was considered mentally retarded.

Among the 35 highly scoring (high-risk) students, 24 children were clinically diagnosed; the other 11 subjects refused to undergo the clinical confirmation process and were therefore excluded from further analysis. Final clinical diagnoses demonstrated that ten of the children had ADHD (ADHD group) and other seven children (non-ADHD group) were normal. The other seven children had psychiatric problems other than ADHD -such as emotional disturbance or tics.

Table 1. Demographic and clinical characteristic of children with and without attention deficit hyperactivity disorder (ADHD)

	ADHD (n = 10)	Non-ADHD (n = 7)	<i>p</i> -value*
Gender	M = 8 (80.0) F = 2 (20.0)	M = 1 (14.3) F = 6 (85.7)	
Age, yr	7.20 ± 0.63	7.5 ± 0.53	0.225
K-ARS			
Attention deficit	12.30 ± 6.73	10.43 ± 5.83	0.561
Hyper activity	11.70 ± 7.70	6.14 ± 4.63	0.110
Total scores	24.00 ± 14.36	16.57 ± 10.23	0.260
K-CBCL, syndrome scales			
Withdrawn	52.30 ± 11.30	59.93 ± 13.35	0.540
Somatic complaints	50.39 ± 7.93	54.68 ± 8.43	0.223
Anxious/depressed	56.80 ± 17.61	54.68 ± 8.43	0.773
Social problems	59.78 ± 17.11	60.28 ± 10.43	0.946
Attention problems	61.21 ± 13.35	63.50 ± 9.80	0.706
Delinquent behavior	53.82 ± 9.77	64.75 ± 13.63	0.072
Aggressive behavior	62.54 ± 15.51	59.06 ± 7.76	0.551
Internalizing problems	52.30 ± 11.30	55.86 ± 5.49	0.455
Externalizing problems	58.20 ± 9.96	60.14 ± 6.99	0.664
Total behavior problems	56.60 ± 12.00	58.43 ± 13.35	0.720

Values are presented as number (%) or mean ± SD.

M: male, F: female, K-ARS: Korean version of the ADHD Rating Scale-IV, K-CBCL: Korean version of Child Behavior Checklist.

**p*-value of independent *t*-test.

Our group comparisons were conducted with ten children with ADHD (eight boys and two girls; mean age, 7.2 ± 0.63 years; range, 6 to 8 years) and seven children without ADHD (six boys and one girl; mean age, 7.6 ± 0.53 years; range, 7 to 8 years); we excluded seven children with other psychiatric problems from further process steps to evaluate the characteristic influence of ADHD itself. Initial rating scale data as well as other demographic information (age and gender) is shown in Table 1, coupled with *t*-tests of potential between-group differences. As a double-blind test, the diagnoses were not notified to anyone involved in the acquisition of activity data until the end of the experiment. The subject children's parents provided signed statements of informed consent. This study was reviewed and is in compliance with the Declaration of Helsinki, and approved by the Institutional Review Board of the Ajou University Medical Center (AJIRB-CRO-07-130).

2. Activity Measurement and Class Information Acquisition

To evaluate the activities of children, an actigraph (LIG Nex1 Co., Ltd., Yongin, Korea) was placed on each child's non-dominant wrist from the beginning to the end of the final lesson (Figure 1). The actigraphs were managed by four assistant researchers who had been trained in the distribution and management of actigraphs, and were described to participating children as 'watches to measure activities.' 3-axial acceleration data from each actigraph was collected for a whole 3 hours at school and recorded in a built-in memory chip at a frequency of 32 Hz.

3. Elementary School in Korea

In Korea, children aged from 6 to 12 attended elementary schools of obligation. Children attend 40-minute courses followed by 10-minute recess periods with a standard curriculum including native language, math, science, ethics, art and physical education (plus some additional subjects according to the grades). For the first and second grade students who were the subjects of this study, the first class begins at 9 a.m. and the last (fourth) class ends at 12 p.m. before lunch. In general, children have assigned seats within a classroom, so there is no need to change seats or classrooms except under special conditions. About 30-40 children attend each class with the same teaching materials while sitting in their own assigned seats. One homeroom teacher is assigned to each class, and he or she is wholly responsible for the class. In this study, three courses including art, language and math were selected as testing environments because they are major in-class courses in the regular elementary school curriculum in Korea, and are with probable class contents and activities.

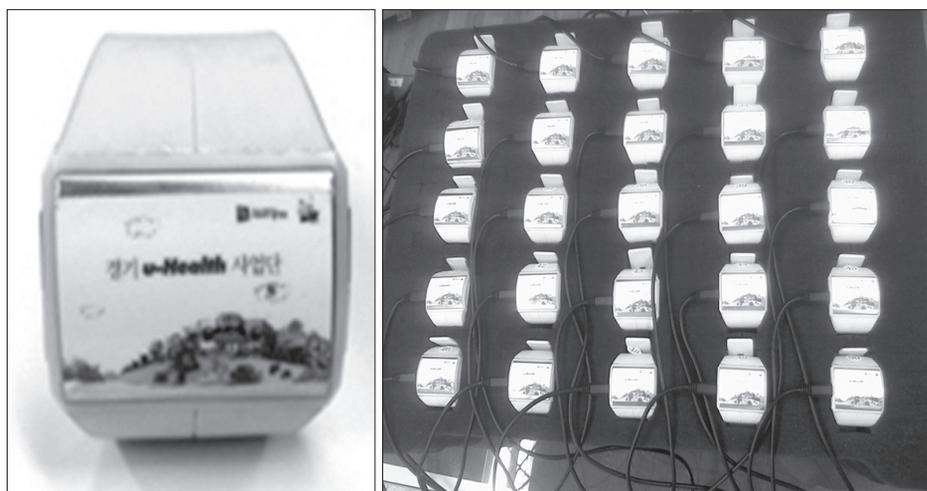


Figure 1. Actigraphs that were used for the activity data acquisition. To evaluate the activities of children, an actigraph (LIG Nex1 Co., Ltd., Yongin, Korea) was placed on each child's non-dominant wrist from the beginning to the end of the final lesson. The actigraphs were managed by four assistant researchers who had been trained in the distribution and management of actigraphs, and were described to participating children as 'watches to measure activities.' The actigraphs were unwrapped after the last lesson via the same procedure. 3-axial acceleration data from each actigraph was collected for a whole 3 hours at school and recorded in a built-in memory chip at a frequency of 32 Hz.

4. Calculation of Activity Features

First, vector summed absolute activity (unit: gravity, G) values were calculated from 3-axial acceleration data measured by actigraphs. Next, activity features such as ratios of mutually exclusive partitioned activity regions (0.5-2.8 G) over the entire activity were extracted in individual 1-minute epochs. Regions from 0.5 G to 2.8 G (0.1 G intervals) and the marginal regions (< 0.5 G and > 2.8 G) were considered. The two thresholds for the marginal activity regions were selected from the activity distribution (smaller than 0.1% of total activity). Here, a ratio for a certain activity level represents the activity counts in a certain activity acceleration region (in gravity) over the whole activity counts of a given time interval.

5. Statistical Analysis

All the activity data in each situation were compared as follows: 1) to compare the activity differences between the ADHD and non-ADHD groups, independent *t*-test or Mann-Whitney *U*-tests were separately applied in different course environments; and 2) to compare activity difference within each group, Friedman tests were conducted for each group (ADHD and non-ADHD), followed by paired *t*-tests or Wilcoxon matched-pairs signed rank tests for paired course comparisons, according to the Shapiro-Wilk normality test. *p*-values of < 0.05 were considered as statistically significant (SPSS ver. 15.0, SPSS Inc., Chicago, IL, USA).

III. Results

1. Between ADHD and Control Groups

To compare the patterns of activity distribution between ADHD and non-ADHD groups, distribution graphs for mean and variance of activity ratio in a 1-min epoch were drawn as shown in Figure 2. As shown here, in the language and math courses, we noted relatively smaller fractions of difference intervals with higher percentages of overlapped areas between groups; on the contrary, in the art course, there were many intervals with significant differences between the two groups, and the percentage of the overlap area was the smallest. Particularly in the art course, the mean ratios of activity acceleration between the groups differed significantly ($p < 0.05$) at the 0.5-0.8 G and 1.3-2.8 G regions (83.3% of the whole regions) and the variance of activity ratios differed significantly at all the regions from the 0.5-2.8 G regions (79.2%), except for the 0.9-1.2 G and 1.5 G regions.

2. Within Each ADHD and Control Group

Activity distributions during three courses were drawn in order to compare the patterns within each group as shown in Figure 3. The ADHD group, but not the non-ADHD group, evidenced many significantly different intervals from low to very high activity acceleration regions between art and languages courses. For example, which regard to the mean ratios of activity acceleration, all the regions of 0.5-0.8 G and

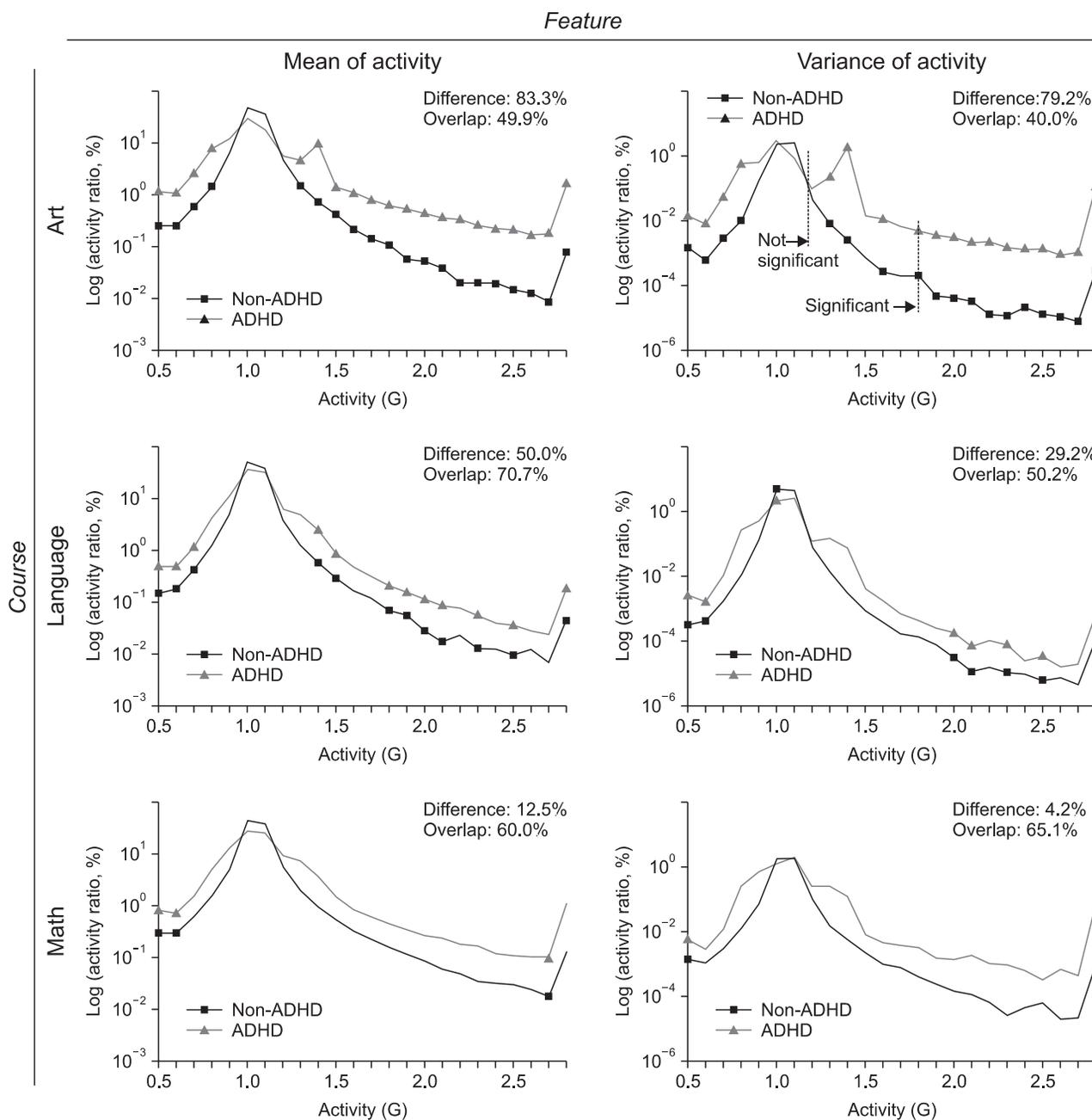


Figure 2. Distribution of activity features for attention deficit hyperactivity disorder (ADHD) and non-ADHD groups according to each course. The x-axis is the degree of activity acceleration (in a gravity unit; G) and the y-axis is the mean (or variance) percentage (%) of activity acceleration of corresponding group members (on a log scale). Each line-pair represents the activity distributions of ADHD and non-ADHD groups at each course such as art (ADHD = 8 and non-ADHD = 4), language (ADHD = 9 and non-ADHD = 5) and math (ADHD = 6 and non-ADHD = 5), respectively. The triangle (and corresponding square) marks on the lines indicate significantly different intervals between the two groups ($p < 0.05$ using an independent t -test or a Mann-Whitney U -test). Here, 'Difference' means the fraction of intervals with a significant difference between the two groups and 'Overlap' means the percentage of the overlap area between the two distributions.

some of the 1.1-2.8 G regions (37.5% of the whole regions) differed significantly between the art and language courses of the ADHD group. Moreover, the tendency became strong for the variance of activity ratios and most intervals of activity speed differed significantly expect for the 0.9-1.0 G, 1.2 G

and 2.3 G regions (83.3%).

IV. Discussion

The objective of this study was to determine whether high-

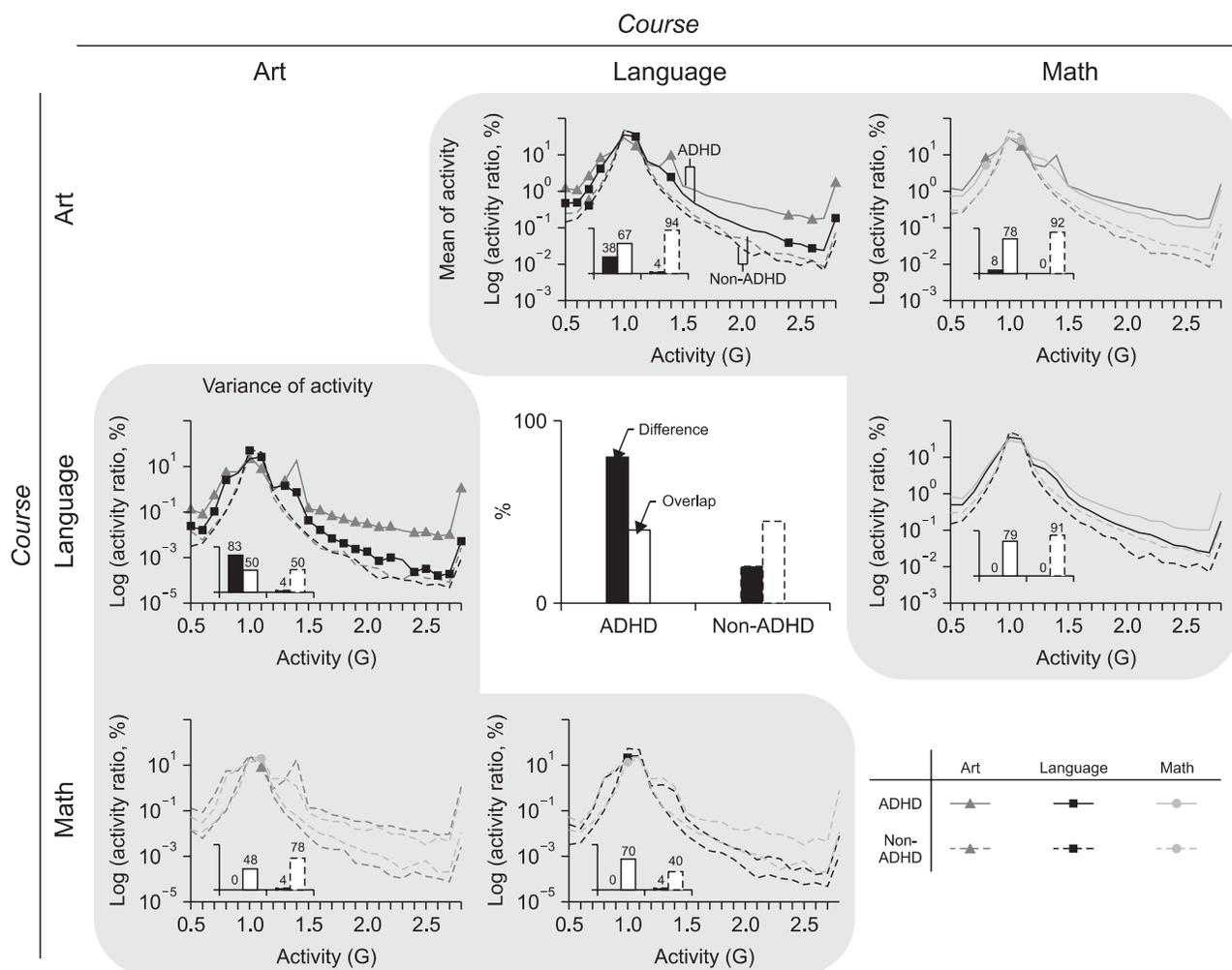


Figure 3. Activity distribution graphs of attention deficit hyperactivity disorder (ADHD) and non-ADHD groups between courses: mean (upper-right) or variance (lower-left) of activity acceleration. In each sub-graph, the activity distributions between two courses were drawn for ADHD (solid lines) and non-ADHD (dotted lines): art vs. language (ADHD = 8 and non-ADHD = 4), art vs. math (ADHD = 6 and non-ADHD = 4) and language vs. math (ADHD = 6 and non-ADHD = 5). Again, the triangle (and corresponding square) marks on the lines indicate significantly different intervals between the corresponding two courses ($p < 0.05$ using a paired t -test or a Wilcoxon matched-pairs signed rank U -test). Each inset bar chart shows the fractions of intervals with significant differences between the two courses in the ADHD and non-ADHD groups (light gray bars) and the percentages of the areas of overlap between the two distributions (dark gray bars).

resolution activity features could provide a sufficient analytical foundation for determining the activity transitions of children with ADHD. From the comparison among the courses, the activity patterns of the ADHD group differed significantly over a wide range of activity levels, as compared to those of the non-ADHD group in addition to their own patterns in other courses, and reflected some circumstantial influences –such as situational demands involving restrictions- on the ADHD group.

1. The Effects of Situational Demands Involving Restrictions

The significant differences in art courses can be explained

by overlapping in the effects of course contents (drawing and music) and types. The native language (reading, writing, speaking and listening) and math (mathematical problems solving) courses were constructed from a pre-defined curriculum according to the teacher’s instructions, and were followed by the students. Children are therefore not likely to leave their seats, and follow instructions except in certain extraordinary situations. On the other hand, the art course consists of drawing and music lessons, and is relatively open and encourages children to be more active, especially during drawing lessons.

According to our results, the patterns of activity expres-

sion could be explained by the effects of situational demands involving restriction. Several previous studies have reported that the characteristics of children with ADHD, such as attention deficit and hyperactivity, were more likely to be expressed in less attentive or supervised situations [10,24]. Thus, it appears likely that the significant difference in activity features for the ADHD group in the art courses is the consequence of the reduced intensity of the teacher's supervision and the consequent increment in the characteristic activities of children with ADHD; the effects of situational demands involving restriction were reported previously [7,8].

2. Activity Distribution: Mean and Variance of Activity Ratios

As a new, high-resolution activity monitoring method, we partitioned children's activity into a wide range of activity regions and ratios from a low level to a high level of activity. We recorded and analyzed the actual magnitude and counts of activity simultaneously, not merely the counts of activity in a time period, and this rendered it possible to look more deeply into the distribution of activities information which was lost as the result of the data summarization process in many previous studies [5-8,10-12,25].

With sufficient information, it was possible to monitor the actual quantity and variance of activity in the form of distribution patterns of the ADHD and non-ADHD groups; whereas the former studies could not show 1) the difference during the morning session between the groups by comparing the percentage difference with the whole mean (or variance) of activity [26] or 2) information regarding degrees of activity such as frequency or intensity [1], through incomplete data compression that was unreflective of intensity or the actual amount of activities determined via ZCM methodology.

Whereas the distribution of mean ratios shows the percent ratio of activity counts in those sectional regions over the entire activity counts, the distribution of variance ratios represents the regions of sectional activity variation across time intervals. That is, the variance shows activity instability, and may reflect other properties such as inattention or impulsivity, which are also diagnostically important for ADHD, in addition to levels of activity and hyperactivity.

3. Limitations

One limitation of this study was the small number of samples. As this research was conducted as a community-based study, the low prevalence of ADHD (3-9%) allowed for only a small number of diagnosed subjects to be included. This analysis was based on a limited number of children,

and thus may have suffered from a relatively large number of type-I errors. Also, inequality or bias regarding subtypes and gender could not be excluded totally. We also allocated the ADHD and non-ADHD groups from the selected high-risk children: the subject children without ADHD (normal) could be subject to a bias toward hyperactive tendencies as compared to the low-risk normal children.

For the aforementioned reasons, care should be exercised in asserting the resultant course-dependent characteristics as clinically factual; still, the basic merit of this study was that it was performed in natural situations rather than in hypothetical or systematically restricted ones. Additionally, we detected clearly differentiated activity patterns between children with/without ADHD that might be ambiguous on questionnaires or the previous traditional activity features, and brought up a new aspect of ADHD monitoring with new activity features that can be monitored over a wide range of activities.

From the intra- and inter-group comparisons in three types of standard courses including art, language and math courses, we determined that the extracted activity patterns for the groups differed quite a lot in the art course, and this was the case for a wide range of activities. Course contents appear to have an important influence on the activity patterns of children with ADHD. Monitoring the actual magnitude and counts of activity across a broad range of activities might make it possible to look more deeply into the distributions or patterns of activities of children with ADHD. This objective actigraphic activity measurement technique might prove useful in obtaining timely changes in activities in children with ADHD.

Conflict of Interest

No potential conflict of interest relevant to this article was reported.

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