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Diagnostic Validity of the Comprehensive Attention Test in Patients With Attention-Deficit/Hyperactivity Disorder

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Objectives: This study verified the diagnostic validity of the Comprehensive Attention Test (CAT) for attention-deficit/hyperactivity disorder (ADHD).

Methods: A total of 336 participants were recruited in this study, including 168 patients with ADHD and 168 control group participants who were one-to-one matched for sex and age. We measured selective attention (visual and auditory), sustained attention, interference-selective attention, divided attention, and working memory in the ADHD and control groups using the CAT. The sensitivity, specificity, positive predictive value, and negative predictive value of the CAT were calculated.

Results: In this study, it was found that the sensitivity and specificity of the CAT were 0.879 and 0.846 in children, 0.855 and 0.838 in adolescents, and 0.800 and 0.733 in adults, respectively.

Conclusion: These results indicate that the CAT has a high diagnostic validity for ADHD from childhood to adulthood.

Keywords: Attention-deficit/hyperactivity disorder; ADHD; Comprehensive attention test; Validity; Sensitivity; Specificity.

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INTRODUCTION

Attention-deficit/hyperactivity disorder (ADHD) is a neurodevelopmental disorder in which an individual's social functioning deteriorates owing to persistent inattention, hyperactivity, and behavioral impulsivity [1]. Globally, the prevalence of ADHD is 7.2% in children [1] and 2.5% in adults [2]. In Korea, the prevalence was reported to be 5.5% in primary schools, 3.5% in secondary schools [3], and 2.4% in adults [4]. Sixty-five percent of children with ADHD still had symptoms in adulthood [5,6]. Given that the pattern and degree of attention change as the brain develops, the symptoms of ADHD also change with age. Ultimately, clinical consideration and evaluation of the patient's age are necessary to make an accurate diagnosis of ADHD [7].

Diagnosis of ADHD is a complex process in which not only biological, neuropsychological, and cognitive but also social factors should be evaluated; thus, a multidimensional and multidisciplinary approach is strongly recommended [8]. The scrupulous interviews with mental status examination to obtain information about medical and psychiatric history, previous and current ADHD and other psychiatric symptoms, self-management abilities, social function, and environmental conditions are crucial processes for ADHD diagnosis. Symptom scales can also be used to evaluate the content and severity of ADHD symptoms. Neuropsychological tests can also be used to collect objective data regarding the current state of attention. It is also important to determine the presence of other coexisting mental or medical disorders [9].

The Continuous Performance Test (CPT) is one of the most commonly used neuropsychological tests to evaluate patients with ADHD and measures vigilance, distractibility, and selective attention [10]. The Test Of Variables of Attention (TOVA), Conners' CPT (CCPT), Gordon Diagnostic System (GDS), and the Korean ADHD Diagnostic System have been used in Korea [11-14]. However, these CPTs had a limitation in that they could measure only simple selective attention. To address this shortcoming of previous CPTs, the Comprehensive Attention Test (CAT) was developed to measure sustained attention (SA), interference-selective attention (ISA), divided attention (DA), and working memory (WM)

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as well as selective attention. The additional advantage of the CAT is that it is standardized from childhood to adulthood and thus can evaluate the attention of a wider range of age groups.

This study investigated the validity of CAT as a diagnostic tool for ADHD in children and adults.

METHODS

Participants

In total, 336 participants were enrolled in this study, including 168 patients with ADHD and 168 controls. For the ADHD group, CAT test data were collected from patients with ADHD who visited child and adolescent psychiatric clinics between 2008 and 2023. A matched group design was used for the control group. We already had a large sample of the normal general population for CAT standardization research in 2018. To use the data from the standardization study as the control group, we conducted one-to-one matching considering the age and sex of the participants in the ADHD group. They lived in the Seoul and Gyeonggi regions; through individual interviews before evaluation, individuals with psychiatric or neurological problems, such as mental retardation, vision, or hearing impairment, were excluded. For the analysis by age, the participants were divided into three groups: children (ages 4–12), adolescents (ages 13–18), and adults (ages 19 years and older).

Assessments

The Comprehensive Attention Test

The CAT [15] used to diagnose ADHD consisted of six subtests: simple selective (visual and auditory) attention, SA, ISA, DA, and WM. The selective attention (visual and auditory: VSA and ASA, respectively) tests measure the ability to focus on and continuously select visual and auditory information as quickly as possible. The SA test measures the ability to maintain or suppress a certain response to repeated stimulation. This test evaluates whether inhibition of a specific stimulus can be maintained. The ISA test, also called "Flanker test," measures the ability to select necessary information from among various distracting information. The DA test estimates the ability to simultaneously process visual and auditory stimuli. The WM test measures the ability to remember multiple visuospatial stimuli for a short period in a forward or backward direction.

CAT is administered differently according to age; VSA, ASA, and SA are administered to children aged 4–5 years, ISA is administered to children aged 6–8 years, and DA and WM are administered to children aged 9 years or older. The CAT provides attention quotients (AQ), which are calculated by converting the results according to a standard of 100 as the mean and 15 as the standard deviation (SD) for the sex and age group of the participant. In the CAT, the results for each subtest were classified as normal, borderline, or abnormal. "Normal" indicates equal to or higher than 1 SD in the normal distribution of the same age and sex group, "borderline" means SD greater than 1 but less than 1.6, and "abnormal" implies equal to or lower than 1.6 SD [15].

The Kiddie-Schedule for Affective Disorders and Schizophrenia-Present and Lifetime Version-Korean version

The Kiddie-Schedule for Affective Disorders and Schizophrenia-Present and Lifetime Version (K-SADS-PL) is a semi-structured interview tool designed to diagnose mental disorders in children and adolescents, according to the diagnostic criteria of the Diagnostic and Statistical Manual of Mental Disorders-Fourth Edition. Kim et al. [16] translated the Korean version of K-SADS-PL (K-SADS-PL-K), which is widely used in Korea.

The Korean version of the Wechsler Intelligence Scale for Children-Fourth Edition

The Korean version of the Wechsler Intelligence Scale for Children-Fourth Edition (K-WISC-IV) [17] is a test adapted for Korean children and standardized from the WISC-IV, which was designed to assess the intelligence of children aged 6–16 years. It consists of 15 subtests, 10 main tests, and 5 supplementary tests, and can be divided into four factors: language comprehension, perceptual reasoning, working memory, and processing speed.

Procedure

This study was approved by the Institutional Bioethics Committee of Sanggye Paik Hospital, Inje University (SGPAIK 2017-06-015-001). Information about the study was provided to the patients and caregivers of the children or adolescents, and written consent was obtained from each participant. To recruit participants from the ADHD group, child and adolescent psychiatrists conducted in-depth clinical interviews, including history taking and mental status examinations, and administered the K-SADS-PL-K. Two experienced clinical psychologists administered the K-WISC-IV, and patients with an intelligence quotient <70 were excluded from the study. In addition, experienced evaluators conducted the CAT one-on-one.

Statistical analysis

T-tests were used to compare differences in continuous vari-

Table 1. Demographic characteristics of the study participants

Characteristics	ADHD			Control		
	Male (n=87, 51.8%)	Female (n=81, 48.2%)	Total (n=168)	Male (n=87, 51.8%)	Female (n=81, 48.2%)	Total (n=168)
Children, 4–12 yr	46 (50.5)	45 (49.5)	91	46 (50.5)	45 (49.5)	91
Adolescents, 13–18 yr	33 (53.2)	29 (46.8)	62	33 (53.2)	29 (46.8)	62
Adults, ≥19 yr	8 (51.8)	7 (48.2)	15	8 (51.8)	7 (48.2)	15
Age (yr)	12.64±4.88	12.54±6.23	12.60±5.55	12.91±5.55	12.56±6.03	12.74±5.77

Data are presented as mean±standard deviation or n (%). ADHD, attention-deficit/hyperactive disorder

ables between the ADHD and control groups. The program used for statistical analyses were performed using SPSS (version 16.0; SPSS Inc., Chicago, IL, USA), and the significance level was set at 0.05 (two-tailed test). The sensitivity, specificity, positive predictive value, and negative predictive value of CAT were calculated using Microsoft Excel (Microsoft Corporation, Redmond, WA, USA).

RESULTS

Demographic information

When examining demographic characteristics, there were no differences in sex and age between the ADHD (n=168) and control groups (n=168). The average age of the ADHD and control groups were 12.60 (5.55 SD) years and 12.74 (5.77 SD) years, respectively (t=0.237, p=0.698). Of 168 patients in both groups, 87 (51.8%) were men. The ADHD group consisted of 91 children, 62 adolescents, and 15 adults (Table 1).

Comparison of the CAT results between the ADHD and control groups

Between the total ADHD and control groups, there were differences in all AQs, except for three (mean reaction time in the ASA, mean reaction time in the SA, and mean reaction time in the DA) (Table 2). As the subtest items of the CAT were administered differently according to age, the results of the VSA, ASA, SA, and ISA for 91 children, ISA for 85 children, and DA and WM for 39 children were compared.

Comparing the results by age group, in the child group, all AQs except for four (mean reaction time in the ASA, SA, DA, and memory span in forward WM) were different. In the adolescent group, all AQs except for three statistics (commission error in the VSA, mean and SD of the reaction time in the ASA) were different. In the adult group, there were differences in 12 statistics between two groups: omission error, mean of reaction time, and SD of reaction time in the VSA (t=2.313, p=0.028; t=2.774, p=0.010; t=5.481, p<0.001); commission error in the ASA (t=2.884, p=0.007); omission error in the SA (t=3.769, p=0.001); omission error, commission error, and SD of reaction time in the ISA (t=4.346, p<0.001; t=4.080, p<0.001; t=3.643, p=0.001); omission error and mean of reaction time and SD of reaction time in the DA (t=3.721, p=0.001; t=2.075, p=0.047; t=3.360, p=0.002); and correct response in the backward WM (t=2.056, p=0.049) (Table 2).

Sensitivity and specificity of the CAT

To evaluate the diagnostic validity of CAT, the sensitivity, specificity, positive predictive value, and negative predictive value were calculated for each age group (Table 3). The highest sensitivity and specificity values were obtained when we determined the final CAT result as "positive" if there were one or more "abnormal" or two or more "borderline" results in the subtests.

Both the sensitivity and specificity tended to decrease with age (Fig. 1). The sensitivity of CAT was 0.879 in children, 0.855 in adolescents, and 0.800 in adults, and its specificity was 0.846 in children, 0.839 in adolescents, and 0.733 in adults (Table 3).

DISCUSSION

This study aimed to verify the diagnostic validity of the CAT in children, adolescents, and adults with ADHD. In this study, we found that the CAT has a high level of diagnostic validity for ADHD because the overall sensitivity and specificity were above 0.800 [18]. The sensitivity and specificity of the CAT generally tended to decrease with age. The sensitivity was 0.879 in the child group, 0.855 in the adolescent group, and 0.800 in the adult group. The specificity was 0.846 in the child group, 0.839 in the adolescent group, and 0.733 in the adult group.

Previously, Seo et al. [19] reported that the sensitivity and specificity of the CAT were 0.827 and 0.444 in children and adolescents with ADHD, which were lower than our results. We speculate that the different outcomes of previous studies could be related to different study designs and participant characteristics. First, the control group in the previous study did not include children or adolescents in the general community. They were recruited at the child and adolescent psychiatric clinic in a general hospital that they had visited for clinical purposes, but they were confirmed to have no serious

Table 2. T-test of attention quotients of the Comprehension Attention Test between ADHD and control group participants by age group

	Children, 4–12 yr				Adolescents, 13–18 yr				Adults, ≥19 yr				Total			
	ADHD	Control	t	p	ADHD	Control	t	p	ADHD	Control	t	p	ADHD	Control	t	p
VSA	(n=91)	(n=91)			(n=62)	(n=62)			(n=15)	(n=15)			(n=168)	(n=168)		
OE	93.20±16.26	105.42±4.39	6.920	<0.001	100.16±10.78	104.95±4.35	3.244	0.002	100.46±12.68	108.93±6.34	2.313	0.028	96.42±14.51	105.56±4.67	7.770	<0.001
CE	100.61±24.48	107.76±9.44	2.601	0.011	108.00±14.09	111.37±7.88	1.644	0.103	106.06±8.89	106.33±7.61	0.088	0.930	103.82±20.36	108.97±8.89	2.999	<0.001
RT M	87.92±16.83	93.21±16.02	2.174	0.031	90.37±12.84	96.66±16.39	2.378	0.019	83.53±14.83	97.93±13.57	2.774	0.010	88.43±15.33	94.91±15.98	3.789	<0.001
RT SD	89.00±21.65	102.62±13.20	5.126	<0.001	95.11±16.34	105.00±10.34	4.025	<0.001	85.00±13.38	107.80±8.96	5.481	<0.001	90.89±19.41	103.96±11.93	7.431	<0.001
ASA	(n=91)	(n=91)			(n=62)	(n=62)			(n=15)	(n=15)			(n=168)	(n=168)		
OE	96.94±19.89	105.35±5.22	3.898	<0.001	100.75±9.39	103.77±4.38	2.290	0.024	97.13±12.53	105.13±8.64	2.035	0.051	98.36±16.19	104.75±5.34	4.851	<0.001
CE	100.39±17.32	108.17±7.58	3.925	<0.001	102.95±9.62	105.75±4.50	2.079	0.041	98.93±9.29	106.13±2.66	2.884	0.007	101.20±14.30	107.10±6.35	4.878	<0.001
RT M	93.92±16.78	93.69±16.13	-0.095	0.925	95.62±14.22	97.40±12.17	0.746	0.457	91.60±15.36	99.40±12.57	1.521	0.139	94.34±15.71	95.57±14.56	0.742	0.459
RT SD	93.28±21.25	103.86±13.32	4.024	<0.001	101.46±16.05	104.30±14.33	1.038	0.301	98.00±17.14	107.86±14.72	1.691	0.102	96.72±19.42	104.38±13.78	4.169	<0.001
SA	(n=91)	(n=91)			(n=62)	(n=62)			(n=15)	(n=15)			(n=168)	(n=168)		
OE	86.90±16.44	104.86±3.72	10.164	<0.001	92.50±14.59	104.85±4.06	6.421	<0.001	97.26±12.40	112.20±9.04	3.769	0.001	89.89±15.77	105.51±4.97	12.245	<0.001
CE	89.93±19.85	113.21±11.85	9.604	<0.001	99.70±17.00	108.00±13.08	3.042	0.003	96.80±15.42	100.73±9.17	0.849	0.403	94.15±18.97	110.17±12.65	9.106	<0.001
RT M	92.29±16.59	92.92±14.69	0.270	0.788	93.54±14.09	99.38±15.05	2.229	0.028	89.40±13.63	96.53±13.86	1.421	0.166	92.50±15.42	95.63±14.98	1.887	0.060
RT SD	88.40±19.57	106.12±11.27	7.471	<0.001	92.11±22.61	103.01±12.35	3.332	0.001	86.06±16.65	91.20±18.39	0.801	0.430	89.56±20.50	103.62±13.05	7.492	<0.001
ISA	(n=85)	(n=85)			(n=62)	(n=62)			(n=15)	(n=15)			(n=162)	(n=162)		
OE	81.91±28.73	110.00±7.83	8.694	<0.001	93.93±14.43	110.33±9.54	7.464	<0.001	92.53±13.69	109.46±6.33	4.346	<0.001	89.89±15.77	105.51±4.97	11.443	<0.001
CE	84.41±24.52	109.50±9.08	8.846	<0.001	94.80±17.89	109.95±8.60	6.007	<0.001	88.73±16.13	121.53±26.63	4.080	<0.001	94.15±18.97	110.17±12.65	11.187	<0.001
RT M	78.38±2.25	91.97±16.37	4.810	<0.001	83.33±11.71	101.33±15.98	7.151	<0.001	88.73±20.71	104.60±30.27	1.675	0.105	92.50±15.42	95.63±14.98	7.691	<0.001
RT SD	70.76±22.90	97.89±17.66	8.647	<0.001	84.25±13.16	104.37±9.37	9.798	<0.001	86.20±13.84	105.60±15.28	3.643	0.001	89.56±20.50	103.62±13.05	12.008	<0.001
DA	(n=39)	(n=39)			(n=62)	(n=62)			(n=15)	(n=15)			(n=116)	(n=116)		
OE	87.46±2.21	106.28±6.87	5.505	<0.001	78.66±32.02	105.45±15.30	5.944	<0.001	71.66±4.52	115.26±2.42	3.721	0.001	87.50±23.68	110.08±8.37	8.504	<0.001
CE	90.82±24.03	105.97±7.63	3.753	<0.001	93.40±15.25	103.85±7.43	4.850	<0.001	97.73±14.45	100.66±6.89	0.709	0.486	88.79±21.95	110.79±12.02	5.946	<0.001
RT M	99.25±22.16	95.69±10.88	-0.901	0.370	91.33±16.62	98.54±11.79	2.785	0.006	84.33±12.72	94.53±14.16	2.075	0.047	81.24±17.73	96.72±18.50	1.927	0.055
RT SD	90.89±24.87	101.30±10.81	2.396	0.020	90.30±16.48	100.16±14.49	3.535	0.001	83.26±15.66	101.46±13.94	3.360	0.002	77.35±20.11	101.08±15.09	5.067	<0.001
WM	(n=39)	(n=39)			(n=62)	(n=62)			(n=15)	(n=15)			(n=116)	(n=116)		
FCR	91.58±21.34	103.05±13.31	2.845	0.006	91.58±15.88	108.00±11.41	6.609	<0.001	98.00±19.35	107.66±12.26	1.634	0.113	92.41±18.29	106.29±12.30	6.780	<0.001
FMS	94.30±22.06	101.20±10.52	1.762	0.084	89.82±16.29	103.90±11.02	5.635	<0.001	97.80±19.56	107.73±11.17	1.708	0.102	92.36±18.89	103.49±10.97	5.486	<0.001
BCR	87.92±21.73	105.02±12.11	4.293	<0.001	96.03±16.95	108.66±14.50	4.458	<0.001	95.60±19.62	108.33±13.78	2.056	0.049	93.25±19.23	107.39±13.63	6.462	<0.001
BMS	91.48±22.58	104.07±9.71	3.198	0.002	98.64±15.59	105.03±12.57	2.510	0.013	97.40±17.61	106.93±12.28	1.720	0.097	96.07±18.60	104.95±11.58	4.363	<0.001

Data are presented as mean±standard deviation. ADHD, attention-deficit/hyperactive disorder; ASA, auditory selective attention test; BCR, backward correct response; BMS, backward memory span; CE, commission error; DA, divided attention test; FCR, forward correct response; FMS, forward memory span; ISA, interference selective attention; OE, omission error; RT M, mean of reaction time; RT SD, standard deviation of reaction time; SA, sustained attention test; VSA, visual selective attention test; WM, spatial working memory test

Table 3. Diagnostic validity of the Comprehensive Attention Test by age group

	Sensitivity	Specificity	PPV	NPV
Children, 4–12 yr	0.879	0.846	0.851	0.875
Adolescents, 13–18 yr	0.855	0.839	0.841	0.853
Adults, ≥19 yr	0.800	0.733	0.750	0.786

NPV, negative predictive value; PPV, positive predictive value

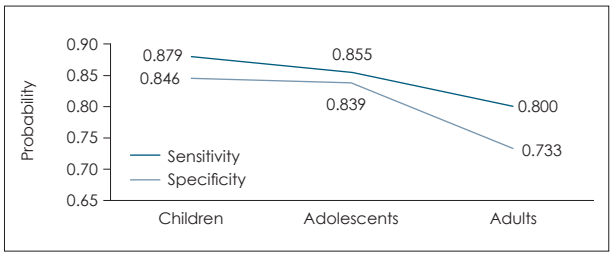

Fig. 1. Sensitivity and specificity of Comprehensive Attention Test by age group.

psychiatric problems. Second, this was a retrospective study that used previous medical records. Third, this study did not use structured diagnostic interviews.

To the best of our knowledge, this study is the first to investigate the diagnostic validity of neuropsychological tests in Koreans with ADHD by age group, particularly including adult group. The sensitivity and specificity in the child and adolescent populations in this study were similar to or higher than those of other CPTs (TOVA sensitivity, 0.857; specificity, 0.700; CCPT sensitivity, 0.670; specificity, 0.733; GDS sensitivity, 0.490–0.590; specificity, 0.810–0.870) [20-22]. By the way, the sensitivity and specificity of adults seemed to be lower than those of children and adolescents. The first possible explanation for the low specificity in adult ADHD may be the characteristics of ADHD in adulthood [23]. The clinical features of adult ADHD are more complex and less typical than those in children and adolescents. This pattern is related to a high rate of comorbidities such as depression, anxiety, and drug addiction in adulthood [24]. A study also found that approximately 80% of adult patients with ADHD had at least one mental disorder, and 46% of patients had comorbid depressive disorder in particular [25]. Therefore, the results of this study appear to reflect complicated and mixed neurocognitive function that may originate from both relatively more complex clinical characteristics of adult ADHD and more frequent comorbid mental disorders. Other common mental conditions in adulthood such as anxiety, mood- and stress-related disorders, drug addiction, and organic brain diseases can cause attention problems. Even some of them could be misdiagnosed as ADHD [1]. For instance, the diagnostic specificity of both depression and ADHD is relatively lower because they have common symptoms such as the inability to concentrate on tasks [23]. Therefore, to correctly diagnose ADHD in adults, it is necessary to collect more comprehensive information including past medical history of children and adolescents from the family members as well as patients, to conduct a more cautious mental state examination, and to obtain more objective data using clinical rating scales or neuropsychological tests.

Psychiatric diagnoses, including ADHD, should not be made through neuropsychological tests alone [26], although the CAT alone provided a positive prediction in 85% of childhood cases, 84% in adolescence, and 75% in adulthood. However, the possibility of an accurate diagnosis may be increased by using the CAT test as a supplementary tool. In addition, the CAT is useful for the verification of ADHD treatment effects [27]. Meanwhile, there have been attempts to use other types of biological tests, such as functional magnetic resonance imaging, to diagnose ADHD [28]. However, these tools have practical limitations for use in actual clinical settings because of their high expense and facility requirements.

We found that patients with ADHD showed lower CAT performance than controls. Particularly for children and adolescents, there were differences between the two groups in most of the statistics for each subtest. Children and adolescents with ADHD are more likely to omit target stimuli and respond to non-target stimuli. In addition, they tended to respond more slowly and with lower consistency. However, the tendency of delayed response in ADHD would be less specific because the response times of the ASA, SA, and DA in children; moreover, the response time of the ASA in adolescents were not different between groups in this study. This finding is in line with previous studies [29,30]. In particular, WM may also be useful for diagnosing children and adolescents with ADHD, which is consistent with previous clinical research [31]. In adults, differences between groups were less consistently observed. In particular, there were statistical differences, mainly related to errors, compared to a few differences in reaction time. This is presumed to be related to the influence of more common comorbid conditions in adults, such as a slower reaction time owing to depression [29] or the influence of aging, such as a slower speed of the finger response.

This study had some limitations. Patients with ADHD were recruited from two child psychiatric clinics in Seoul, which resulted in a lack of representativeness. In addition, the diagnostic validity was relatively low in adults. Additional tests

or scales would be helpful for diagnosing comorbid conditions and ADHD in adults more accurately. In this study, only a minimum sample of adults in their 40s was available; therefore, further studies with a sufficient number of adult participants are necessary to confirm the results of this study. Additionally, the K-SADS-PL-K was administered to the ADHD group but not to the control group. Future studies with a control group ascertained by the structural diagnostic interview tool are necessary. Future sex analyses would be helpful to determine the influence of sex differences.

The significance of this study is as follows: First, the CAT, which has sufficient sensitivity and specificity, can be a useful tool in the complex diagnostic processes of children, adolescents, and adults with ADHD. Second, the CAT, which measures several aspects of attention, including VSA or ASA, SA, ISA, DA, and WM, can complement the limitations of previous CPTs tests. This test would be useful for measuring treatment effects pre- and post-application.

CONCLUSION

In this study, we found that the CAT had a sufficient sensitivity and specificity, which were higher than 0.800 in all age groups except for specificity in the adult group, as a diagnostic tool for ADHD from childhood to adulthood.

Availability of Data and Material

The datasets generated or analyzed during the study are available from the corresponding author on reasonable request.

Conflicts of Interest

Hannah Huh is an employee of the company that produces the CAT. All remaining authors have declared no conflicts of interest.

Author Contributions

Conceptualization: Hanik Yoo. Data curation: Hannah Huh. Formal analysis: Hannah Huh, Hanik Yoo. Investigation: Woo Young Kim, Eun Kyoung Lee, Bum-Sung Choi, Bongseog Kim, Hanik Yoo. Methodology: Hanik Yoo. Project administration: Hannah Huh. Resources: Bum-Sung Choi, Bongseog Kim, Hanik Yoo. Supervision: Hanik Yoo. Validation: Hyunju Lee, Hanik Yoo. Visualization: Hyunju Lee. Writing—original draft: Hyunju Lee. Writing—review & editing: Hanik Yoo.

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