



Developmental Trajectories of Attention in Normal Korean Population

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Objectives: This study aimed to investigate the trajectory of change of diverse attention and working memory in Koreans from 4 to 40 years of age.

Methods: The data of 912 subjects from 4 to 15 years of age obtained from a previous standardization study of the computerized comprehensive attention test were merged with the newly obtained data of 150 subjects aged 16 to 40 years from this study. We evaluated the various kinds of attention, in which each subtest had five indicators. Working memory, with parameters such as number of correct responses and span, was also measured.

Results: Our findings indicated that attention developed as age increased, and it decreased or was maintained after a certain age. Selective and sustained attention developed rapidly in children and adolescents, until mid-teens or 20 s when it ceased development. Divided attention, however, developed up to approximately age 20. In addition, working memory developed until mid-teens or 20 s.

Conclusion: We presented the standardized data on diverse kinds of attention and working memory in children, adolescents, and adults in Korea. We could recognize any patterns of change in attention and working memory with increasing age.

Key Words: Attention; Continuous performance task; Working memory; Neuropsychologic test; Development.

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INTRODUCTION

Attention is one of the fundamental higher cognitive abilities and cannot be explained by a single concept. Although neuroscientists and clinicians have suggested divergent opinions about its definition and scope, several classifications have been widely used to categorize the functions and phenomena of attention. These include: 'focused attention' that indicates the degree of attention by a specific stimulus, 'selective attention' that means paying attention to a stimulus among several stimuli, 'sustained attention' that means continuously maintaining attention to the stimulus until the given task has been completed, and 'divided attention' that gives attention to several stimuli at the same time [1]. Attention is a lengthy process, from preparation for concentration on the given stimuli, to understanding the meaning or value of the stimuli, and to choosing the appropriate stimuli according to the context. Thus, attention is important in completing

information processing [2].

Working memory is a cognitive capability that not only stores, but also processes information for a short period of time. It occurs in a context-oriented manner according to incoming stimuli or previously stored information [3]. Working memory is one of the crucial factors in the performance of executive function [3], which is defined as the ability to plan, organize information, and solve problems appropriately. There have been studies on the interactions between working memory and attention. Attention acts as a 'gatekeeper' for working memory by choosing and encoding information that is relevant to current processing goals. In addition, attentional processes help in the active maintenance of information when spatial working memory is employed [4].

A lack of attention and working memory leads to difficulties in high-level functions such as self-management and learning. Since attentional deficits are a common symptom of many mental disorders [1], evaluation of attention has been used to determine the diagnosis, progress, and sequel of diverse mental disorders [5]. In particular, attention-deficit/hyperactivity disorder (ADHD) is a neurodevelopmental

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disorder characterized by attention deficit, hyperactivity, and impulsivity. The prevalence of ADHD in school-aged children is known to be approximately 5% [6]. Patients with ADHD suffer from academic and social difficulties and as attention changes naturally through aging, ADHD symptoms are also altered. However, at least 60% of ADHD symptoms last into adulthood [7]. In order to determine objective levels of attention in people with or without attention deficits, it is necessary to use standardized normative data from children to adults.

Although controversy remains, the most common method to evaluate attention is the computer-based continuous performance test (CPT), which measures correct response count, omission error, commission error, and reaction time to the target stimuli. The test is known to be useful to distinguish children with ADHD from neurotypical children and to monitor drug effects [8]. However, it has some limitations, especially when assessing children with strong intellectual abilities or seniors [9].

The computerized comprehensive attention test (CAT) evaluates various and comprehensive types of attention and working memory in children and adolescents. The CAT was standardized and has been used in Korea [10]. Since it is computerized, the CAT demonstrates higher inter-rater reliability and offers more accurate and sensitive data than pencil and paper tests about response time. The CAT is composed of six subtests to measure focused attention, attentional capacity, sustained attention, divided attention, and visuospatial working memory. These subtests have been widely used to evaluate both normal and ADHD groups [11,12]. In addition, the sustained attention and working memory tests have been known to be effective in screening children with ADHD [13]. Although the CAT has been used to evaluate different levels of attention in Korea [14], it is standardized only for ages 4–15.

Attention typically develops gradually with age, stops in adolescence, remains until a certain age, and decreases along with the decline of brain function. However, we have limited data on the age-related trajectories of various types of attention in Korea, as the normative data of late adolescence and adults have not yet been obtained.

Therefore, in the present study, we administered the CAT to older adolescents and adults and merged the data with previous normative data of children and young adolescents. The complete data were then analyzed to identify how attention and working memory change with age.

METHODS

Participants

We used both the previous CAT standardization data from

2009 and new data for this study. The previous data had been collected from 912 elementary, middle, and high school students aged 4 to 15, excluding those with intellectual disabilities, schizophrenia, other psychoses, organic mental disorders, and vision or hearing problems in Seoul and the metropolitan area [10]. Additional CAT data from 150 healthy subjects aged 16 to 40 and without exclusion conditions were obtained in Seoul and the metropolitan area. Finally, the data of 1062 people [552 males (52.0%) and 510 females (48.0%)] were analyzed (Table 1).

Materials

The computerized CAT

The CAT was used to evaluate the attention and working memory of study subjects. The CAT consists of selective attention (visual and auditory), sustained attention to response, flanker, divided attention, and spatial working memory tests. The tests have been standardized for children aged 4 to 15 and confirmed to be reliable and valid [9,14]. In the selective attention test, the subject presses the button as quickly as they see/hear the given targets. In the sustained attention test to response task (SA), the subject presses the button when a picture appears, unless it is an 'X.' In the flanker test, the subject responds to stimuli in the center box while ignoring the interference boxes. In the divided attention test (DA), the subject remembers the picture and sound of the previous target and presses the button when the previous target reappears. In the spatial working memory test, the subject remembers the sequence and locations the highlighted boxes, then presses

Table 1. Demographic data of study subjects

Age/age group (years)	Male (number)	Female (number)	Total (number)
4	27	24	51
5	31	30	61
6	52	41	93
7	54	51	105
8	67	56	123
9	31	40	71
10	37	25	62
11	29	31	60
12	37	29	66
13	44	33	77
14	48	28	76
15	29	38	67
16–19	11	15	26
20–29	28	34	62
30–39	12	14	26
40–49	15	21	36
Total	552	510	1062

the boxes in the order they appear and in the reverse order.

Except for the working memory test, each subtest had five indicators [commission errors (CE), omission errors (OE), mean reaction time (RT mean), standard deviation of reaction time (RT sd), and sensitivity coefficient (d')]. The CE indicates the number of responses to the stimuli of the non-target, and the OE indicates the number of missed responses to the target stimuli. The RT mean refers to the average time taken to respond to the target stimuli, and the RT sd reflects the response time variability to the target stimuli. The d' reflects how effectively the target stimuli are distinguished from the non-target stimuli. The high point of the d' suggests a high level of signal-noise differentiation. The spatial working memory task evaluates the degree of recall of the sequence of the visual stimuli in order and in reverse order and has two indicators (correct response number and memory span).

Procedure

This study was approved by the Institutional Review Board at Konkuk University (No. 7001355-201711-E-059). The CAT required 40 to 60 minutes to complete.

Analysis

The data were analyzed using SPSS for Windows (version 21.0; IBM Corp., Armonk, NY, USA). Standardization data were described, and statistical significance was applied at p<0.05. SigmaPlot (version 14.0; Systat Software Inc., San Jose, CA, USA) and Origin® (version 2018b; OriginLab Corp., Northampton, MA, USA) were used to obtain regression equations and graphs of all parameters.

RESULTS

The normative data of the CAT for 1062 Korean children, adolescents, and adults are presented in Table 2 and 3. The mean and standard deviation (SD) of the OE, CE, RT mean, RT sd, and d' values by age and gender are also shown.

The graphs of the regression model showed that the relationship between age and task results was non-linear (Supplementary Figs. 1-17 in the online-only Data Supplement). In order to find the changes of attention with age, we described to five indicators of subtests, except in the spatial working memory test. The working memory test was described separately because of different types of indicators.

Visual selective attention test (VSA) and auditory selective attention test (ASA)

CE and OE

The CE and OE of the visual selective attention test (VSA)

Table 2. Mean and SD of the CAT in the Korean children and adults (male)

Age	VSA					ASA					Flanker test					SA					DA					Spatial working memory test										
	CE	OE	RTm	RTsd	d'	CE	OE	RTm	RTsd	d'	CE	OE	RTm	RTsd	d'	CE	OE	RTm	RTsd	d'	CE	OE	RTm	RTsd	d'	CE	OE	RTm	RTsd	d'	FCR	FSN	BCR	BSN		
4	47.31	18.98	672.42	245.94	2.16	35.93	46.25	899.18	395.81	0.97	-	-	-	-	-	33.74	34.00	730.23	294.73	1.27	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
5	39.49	13.44	606.46	216.78	2.43	28.49	29.33	787.88	329.34	2.02	-	-	-	-	-	31.10	25.14	647.75	270.88	1.55	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
6	33.72	10.63	528.18	184.39	2.66	23.55	21.42	712.31	286.33	2.57	-	-	-	-	-	28.88	20.44	590.86	251.04	1.78	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7	28.79	8.76	468.34	159.52	2.88	19.80	16.50	653.42	253.85	2.94	22.86	5.80	581.18	149.73	1.99	26.73	17.21	545.72	232.18	2.01	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8	24.58	7.44	426.74	140.42	3.09	16.90	13.23	608.27	229.32	3.21	20.26	4.49	500.83	121.63	2.39	24.68	14.87	510.33	214.29	2.22	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9	20.99	6.46	398.85	125.75	3.28	14.61	10.93	574.38	210.79	3.41	17.05	3.53	455.98	102.32	2.70	22.70	13.09	482.99	197.36	2.43	13.64	15.19	716.16	292.99	1.37	12.84	11.21	699.57	277.47	1.55	7.02	5.08	7.62	5.52		
10	17.92	5.71	380.61	114.48	3.47	12.77	9.26	549.68	196.79	3.57	14.07	2.91	431.00	90.91	2.93	20.80	11.69	462.28	181.41	2.62	11.70	8.86	685.85	264.52	1.82	11.70	8.86	685.85	264.52	1.82	7.51	5.39	8.09	5.83		
11	15.30	5.12	369.08	105.83	3.65	11.27	8.00	532.43	186.22	3.69	11.81	2.55	418.88	84.80	3.06	18.99	10.57	446.99	166.42	2.81	10.19	7.22	673.08	252.37	2.10	10.19	7.22	673.08	252.37	2.10	7.90	5.71	8.31	5.99		
12	13.06	4.64	362.19	99.18	3.82	10.02	7.03	521.18	178.24	3.79	9.66	2.26	411.90	80.59	3.14	17.26	9.65	436.13	152.41	2.98	8.32	5.95	659.87	239.66	2.38	8.32	5.95	659.87	239.66	2.38	8.16	5.95	8.41	6.07		
13	11.15	4.24	358.54	94.08	3.97	8.96	6.25	514.72	172.21	3.88	7.90	2.09	409.54	78.50	3.19	15.62	8.88	428.84	139.36	3.15	6.78	5.17	649.14	229.20	2.60	6.78	5.17	649.14	229.20	2.60	8.37	6.16	8.47	6.12		
14	9.31	3.87	357.08	89.68	4.14	7.94	5.56	511.91	167.11	3.96	6.47	1.95	410.08	77.29	3.19	13.84	8.14	424.00	125.64	3.32	5.53	4.63	639.37	219.55	2.77	5.53	4.63	639.37	219.55	2.77	8.53	6.32	8.50	6.14		
15	7.95	3.59	357.44	86.78	4.27	7.18	5.06	512.54	163.80	4.01	5.45	1.86	412.06	76.93	3.18	12.37	7.59	422.16	114.67	3.47	3.60	3.86	616.50	195.94	3.10	3.60	3.86	616.50	195.94	3.10	8.84	6.60	8.55	6.15		
16-19	5.09	3.00	363.64	81.82	4.60	5.49	4.06	525.53	158.33	4.15	3.24	1.74	423.62	78.27	3.05	8.60	6.38	425.9309	88.77	3.82	2.65	3.88	598.85	170.20	3.25	2.65	3.88	598.85	170.20	3.25	9.16	6.70	8.62	6.08		
20s	1.82	2.17	386.20	78.09	5.01	3.07	2.84	573.76	154.45	4.33	1.22	1.74	454.70	85.01	2.63	2.58	4.66	452.9951	62.45	4.30	2.52	4.74	655.35	201.51	3.02	2.52	4.74	655.35	201.51	3.02	9.30	6.46	8.71	5.94		
30s	0.37	1.57	415.28	77.25	4.75	1.24	2.08	624.12	153.66	4.46	0.77	1.88	489.62	93.89	2.09	0.74	3.37	487.0599	104.31	4.16	2.52	4.74	655.35	201.51	3.02	2.52	4.74	655.35	201.51	3.02	9.30	6.46	8.71	5.94		
40s	0.15	1.39	427.20	77.20	4.26	0.67	1.88	637.81	153.62	4.51	0.89	1.95	503.04	97.51	1.87	2.70	2.96	498.0693	159.49	3.74	2.51	5.19	718.19	245.90	2.85	2.51	5.19	718.19	245.90	2.85	9.32	6.31	8.75	5.94		

ASA: auditory selective attention test, BCR: backward correct response, BSN: backward span, CAT: comprehensive attention test, CE: commission error, d': sensitivity coefficient, FCR: forward correct response, FSN: forward span, OE: omission error, RT m: Mean of reaction time, RT sd: standard deviation of reaction time, SA: sustained attention test to response task, VSA: visual selective attention test

Table 3. Mean and SD of the CAT in the Korean children and adults (female)

Age	VSA				ASA				Flanker test				SA				DA				Spatial working memory test										
	CE	OE	RTm	RTsd	d'	CE	OE	RTm	RTsd	d'	CE	OE	RTm	RTsd	d'	CE	OE	RTm	RTsd	d'	CE	OE	RTm	RTsd	d'	FCR	FSN	BCR	BSN		
4	23.74	19.64	725.18	272.22	2.77	25.27	51.33	940.64	401.04	1.07	-	-	-	-	-	23.05	39.38	855.20	287.30	1.86	-	-	-	-	-	-	-	-	-	-	-
5	20.58	11.31	647.34	215.48	3.00	22.33	28.18	843.99	334.13	2.27	-	-	-	-	-	21.31	23.50	733.88	263.15	2.09	-	-	-	-	-	-	-	-	-	-	-
6	18.16	7.69	564.99	179.76	3.20	18.17	18.20	774.59	290.09	2.87	-	-	-	-	-	19.83	16.59	656.29	243.01	2.29	-	-	-	-	-	-	-	-	-	-	-
7	16.03	5.58	502.71	153.46	3.38	14.62	12.47	717.47	256.30	3.26	14.02	6.07	631.67	164.53	2.53	18.42	12.59	598.31	223.78	2.48	-	-	-	-	-	-	-	-	-	-	-
8	14.14	4.29	459.28	134.10	3.56	11.84	8.97	671.01	230.37	3.54	12.18	4.41	547.61	127.62	2.75	17.05	10.12	555.00	205.47	2.66	-	-	-	-	-	-	-	-	-	-	-
9	12.48	3.44	429.85	119.84	3.73	9.71	6.72	633.77	210.47	3.74	10.01	3.21	490.65	101.89	3.08	15.74	8.51	522.63	188.07	2.83	14.78	14.60	748.97	270.33	1.18	6.69	4.77	6.16	4.85	-	-
10	11.02	2.87	410.24	109.34	3.88	8.06	5.23	604.48	195.20	3.90	8.10	2.46	457.63	86.34	3.37	14.48	7.43	498.45	171.60	2.99	12.39	11.06	731.14	259.97	1.69	7.33	5.01	6.71	5.27	-	-
11	9.72	2.48	397.46	101.61	4.03	6.79	4.22	581.99	183.49	4.02	6.71	2.02	440.46	77.79	3.56	13.27	6.69	480.38	156.03	3.14	9.90	8.95	716.33	251.31	2.02	7.79	5.28	7.16	5.48	-	-
12	8.58	2.20	389.43	95.92	4.18	5.78	3.52	565.30	174.50	4.12	5.41	1.69	429.13	71.65	3.71	12.12	6.16	466.88	141.39	3.29	7.73	7.48	702.48	243.16	2.28	8.13	5.53	7.53	5.60	-	-
13	7.57	2.01	384.73	91.72	4.31	4.98	3.03	553.50	167.60	4.20	4.49	1.49	423.94	68.38	3.79	11.01	5.78	456.80	127.66	3.43	6.03	6.33	688.08	234.60	2.49	8.36	5.72	7.79	5.67	-	-
14	6.56	1.84	382.17	88.27	4.45	4.26	2.65	544.99	161.66	4.28	3.63	1.34	421.49	66.22	3.82	9.82	5.48	448.35	113.09	3.57	5.10	5.63	676.30	227.54	2.63	8.55	5.89	8.00	5.71	-	-
15	5.79	1.74	381.64	86.10	4.57	3.76	2.42	541.12	157.75	4.33	3.03	1.26	421.38	65.28	3.82	8.83	5.29	442.95	101.33	3.69	4.55	5.12	665.50	220.99	2.74	8.68	6.01	8.16	5.73	-	-
16-19	4.06	1.59	385.62	82.66	4.85	2.78	2.10	544.28	151.08	4.45	1.76	1.16	428.06	65.75	3.67	6.27	5.00	434.18	72.75	3.98	3.95	4.41	639.64	204.78	2.90	8.92	6.23	8.44	5.75	-	-
20s	1.77	1.52	404.39	80.44	5.20	1.73	2.10	581.03	146.07	4.62	0.63	1.26	452.60	72.45	3.06	2.05	4.87	428.21	38.00	4.36	3.74	4.35	615.33	185.69	2.93	9.11	6.32	8.62	5.74	-	-
30s	0.50	1.60	490.04	80.04	4.99	1.26	2.45	609.01	144.94	4.73	0.37	1.53	483.08	82.22	2.23	0.31	5.02	427.06	63.40	4.21	3.72	5.05	663.58	202.12	2.75	9.15	6.14	8.54	5.70	-	-
40s	0.25	1.64	440.75	80.03	4.59	1.18	2.64	600.38	144.88	4.77	0.43	1.65	495.26	86.31	1.89	1.28	5.11	427.00	108.38	3.82	3.72	5.43	722.79	228.77	2.66	9.13	6.02	8.47	5.68	-	-

ASA: auditory selective attention test, BCR: backward correct response, BSN: backward span, CAT: comprehensive attention test, CE: commission error, d': sensitivity coefficient, FCR: forward correct response, FSN: forward span, OE: omission error, RTm: Mean of reaction time, RTsd: standard deviation of reaction time, SA: sustained attention test to response task, VSA: visual selective attention test

and auditory selective attention test (ASA) had a similar tendency with concave downward shaped graphs. In the VSA, the CE and OE were at the maximum points at age 4 in both males and females (CE: M=47.31, F=23.74; OE: M=18.98, F=19.64). For males, both the CE and OE decreased with age, whereas only the CE decreased for females. Although errors declined sharply until ages 16-19, they remained stable past those ages. The OE of females decreased with age and was the lowest in the 20 s (OE=1.52) (Supplementary Fig. 1 in the online-only Data Supplement). In the ASA, both the CE and OE were at their maximum at age 4 (CE: M=35.93, F=25.27; OE: M=46.25, F=51.33). They also decreased with age, and declined slightly after ages 16-19. However, the OE of females was at its minimum at ages 16-19 (OE=2.10), then increased slightly (Supplementary Fig. 4 in the online-only Data Supplement).

RT and RT sd

The RT and RT sd of the VSA showed a similar tendency to the RT and RT sd of the ASA. In the VSA, the RT mean at age 14 and 15 were the fastest for males and females, respectively (M=357.08 ms, F=381.64 ms). The RT sd decreased with age; it declined sharply until early teenage years but remained almost unchanged after (Supplementary Fig. 2 in the online-only Data Supplement). In the ASA, the RT at age 14 was the fastest for males (511.91 ms) and age 15 for females (541.12 ms). The RT sd decreased until age 10 and showed little change after that (Supplementary Fig. 5 in the online-only Data Supplement). In the VSA, females responded slower than males (t=-3.253, p=0.001), while no significant difference was found in the ASA.

d'

In the VSA, the mean of d' increased until approximately age 20 in both males and females, which was followed by a decrease (Supplementary Fig. 3 in the online-only Data Supplement). In the ASA, though the d' increased with age, the development was rapid until the early teenage years, and then increased slightly (Supplementary Fig. 6 in the online-only Data Supplement).

Flanker test

CE and OE

The flanker test was administered to subjects aged 7 and older. The youngest participants showed the most errors (CE: M=22.86, F=14.02; OE: M=5.80, F=6.07). The CE decreased sharply until ages 16-19 and declined slightly until the approximately age 30 (M=0.77, F=0.37). The males demonstrated significantly higher CE than the females (t=4.981, p=0.000).

The males and females aged 16 to 19 showed the lowest OE ($M=1.74$, $F=1.16$) (Supplementary Fig. 7 in the online-only Data Supplement).

RT and RT sd

There was a similar tendency between the graphs of the RT and RT sd in the flanker test. The RT mean at age 7 was the slowest ($M=581.18$, $F=631.67$), but males at age 13 and females at age 15 were the fastest ($M=409.54$, $F=421.38$). Similarly, the SDs in both the males and females were the highest at age 7 ($M=149.73$, $F=164.53$) and the lowest at age 15 ($M=76.93$, $F=65.28$) (Supplementary Fig. 8 in the online-only Data Supplement).

d'

The minimum points were at age 7 ($M=1.99$, $F=2.53$). The peaks were at age 13 for males and age 14 for females ($M=3.19$, $F=3.82$), then they sharply decreased (Supplementary Fig. 9 in the online-only Data Supplement). The d' of females was significantly higher than that of males ($t=-3.565$, $p<0.001$).

Sustained attention test to response task (SA)

CE and OE

The CE and OE of the SA showed the maximum point was at age 4 (CE: $M=33.74$, $F=23.05$; OE: $M=34.00$, $F=39.38$). The CE sharply dropped until age 16 to 19, where it decreased slightly, and then increased again. The OE in males decreased with age; however, in females, it was its minimum in their 20s (OE= 4.87) and remained stable (Supplementary Fig. 10 in the online-only Data Supplement).

RT and RT sd

In both males and females, the RT mean was the slowest at age 4 ($M=730.23$, $F=855.20$). The RT of males was fastest at age 15 (RT= 422.16), and in females, there was a sharp decline until mid-teenage years, which then decreased slightly. The RT sd was lowest in the 20s for both males and females ($M=62.45$, $F=38.00$) (Supplementary Fig. 11 in the online-only Data Supplement).

d'

The mean of the d' increased until the 20s ($M=4.30$, $F=4.36$), which was followed by a decrease (Supplementary Fig. 12 in the online-only Data Supplement).

Divided attention test (DA)

CE and OE

The DA was applied to subjects aged 9 years and older. Both

the CE and OE had a peak at age 9 (CE: $M=13.64$, $F=14.78$; OE: $M=15.19$, $F=14.60$). The CE decreased with age but stayed at a similar level after approximately age 20, whereas the OE had a minimum point at ages 16–19 for males and in the 20s for females ($M=3.86$, $F=4.35$) (Supplementary Fig. 13 in the online-only Data Supplement).

RT and RT sd

At age 9, the RT mean was the slowest ($M=716.16$, $F=748.97$), while the fastest was at approximately age 20 ($M=598.85$, $F=615.33$). The RT gradually increased with age following their 20s. The tendency of the RT sd was similar to that of the RT, which decreased until their 20s ($M=170.20$, $F=185.69$) (Supplementary Fig. 14 in the online-only Data Supplement).

d'

The mean of the d' increased until approximately age 20 in both males and females ($M=3.25$, $F=2.93$), and decreased gradually with age after that (Supplementary Fig. 15 in the online-only Data Supplement).

Spatial working memory test

Forward

The graphs of the correct response number and memory span were shaped concave downward. In males, though the correct response gradually increased with age, it remained stagnant from the 20s. In females, it was the highest in the 30s (Supplementary Fig. 16 in the online-only Data Supplement). The memory span was the widest in the 20s ($M=6.70$, $F=6.32$). The graphs then flattened out (Supplementary Fig. 17 in the online-only Data Supplement).

Backward

The correct response and memory span of the backward test were similar to the forward test. In males, the correct response drastically increased until mid-teenage years and increased slightly after that, becoming stable. The highest correct response in females was in their 20s. The largest span was at ages 16–19 for males and females ($M=6.15$, $F=5.75$). After the peaks, the values remained steady (Supplementary Figs. 16 and 17 in the online-only Data Supplement).

DISCUSSION

Through this study, we acquired the standardized data on various kinds of attention and working memory in children, adolescents, and adults in Korea. Furthermore, we observed how attention and working memory change with age.

VSA and ASA

Although the VSA and ASA, as well as the flanker test, revealed selective attention capability [10], there might be some differences according to the results of the present study. Both the CE and OE in the VSA declined with age and showed a ceiling effect after approximately age 20 (Supplementary Fig. 1 in the online-only Data Supplement); however, the OE might be lower than the CE. Additionally, female teenagers had a tendency of lower CE than males. In the ASA, we also observed a similar tendency (Supplementary Fig. 4 in the online-only Data Supplement). Many studies using the CPT, on which the VSA and ASA were based, have reported analogous results to this study. In a study of 816 children and adolescents between the ages of 9 and 17, both the OE and CE tended to decrease with age [11]. The same tendency was also observed in the study of 514 girls aged 5 to 12 [15]. A cohort study that tracked the CPT performance of children at age 8 ($n=435$) also showed that the OE decreased rapidly after age 6. In particular, the most rapid changes were shown between ages 8 and 10, with more gradual changes occurring between ages 10 and 13 [16]. This pattern was similar to results from our study. A CPT study in adults showed relatively high levels of the correct responses, which corresponded with our study [17].

In the VSA, the RT decreased until early teenaged years and then increased with age. In only the VSA, females responded slower than males. The RT sd of the VSA and ASA were drastically reduced until ages 14 and 15, then maintained at a similar level. In the previous CPT studies of children and adolescents, the RT and RT sd decreased with age [11,15], and females showed longer RT than males, which is similar to our study (Supplementary Figs. 2 and 5 in the online-only Data Supplement) [11].

The d' of the VSA reached the highest value in the mid-20s and gradually declined after that, while the curve of the d' in the ASA sharply increased up to age 12 (Supplementary Figs. 3 and 6 in the online-only Data Supplement). In a previous CPT study of children and adolescents, the d' value increased with age, which is consistent with our study [11,15,18]. When comparing adolescents (mean age=14.0 years) to adults (mean age=41.3 years), adolescents had higher d' ($p < 0.01$) [17]. Normally the d' is a good parameter of selective attention because it implies how the subject distinguishes the target from the non-target stimuli [10]. Thus, these findings indicate that selective attention develops rapidly in children and adolescents and minimally develops or even decreases from the late teenaged years to early 20s. In the ASA, however, the d' sharply increased until age 12, and gradually increased after that. This result was contrary to a precedent study, which used a visual task, reporting higher d' in ado-

lescents [17]. This distinction might be a result of the different tasks used; however, because there has not been a study that uses auditory selective stimuli, further studies are needed to obtain confirmative results. There was also a study showing that females have significantly higher values than males in the d' [11]. In this study, females had higher values than males; however, this was not a statistically significant difference.

Females are thought to perform better and more cautiously than males because the female's d' and RT mean were higher in the selective attention tests. This could be related with the well-known fact that boys with ADHD have more hyperactive and impulsive symptoms and comorbid externalizing disorders than girls [19]. However, further research is necessary to obtain more certain results.

Flanker test

The flanker test is an effective test for measuring interference-selective attention, and it has been known to effectively distinguish ADHD from normal children [20]. The CE in males dropped sharply by ages 16–19, and gradually decreased after that. The CE of males was higher than that of females, decreased slightly until mid-20s, and remained stable after approximately age 30. The OE in both males and females decreased rapidly until age 10, staying almost unchanged after that (Supplementary Fig. 7 in the online-only Data Supplement). The tendency of the RT was similar to that of the VSA. It decreased until ages 13 and 14, then gradually increased in both males and females. The RT sd declined sharply and gradually increased after teenaged years (Supplementary Fig. 8 in the online-only Data Supplement). For d' , females were higher than males, and the peaks of d' were reached at ages 16–19 in males and at age 14 in females, then declined in both (Supplementary Fig. 9 in the online-only Data Supplement). Higher CE and lower d' in males than females could be due to the males' more impulsive tendencies. A previous flanker test study of the ages 20–70 revealed that the RT increased with age, but the error rate did not change significantly [21]. It implied that though old age could be related to slow speed, it would not be associated with accuracy. Similarly, the CE of the ages 20–40 in our study was rarely variable.

SA

The CPT, such as the SA, VSA, and ASA, that measured sustained attention has been widely used to evaluate patients with ADHD [11,12]. Though the application should be conducted with caution, sustained attention could be effective in screening children with ADHD [18].

In the present study, the CE of the SA gradually decreased until approximately age 30, and slightly increased after that.

However, the OE decreased relatively quickly until age 10, and then was maintained (Supplementary Fig. 10 in the online-only Data Supplement). As CE is known to be related to a lack of inhibition against impulsivity [22], inhibition likely develops into the 30s. Carriere et al. [23] also suggested that sustained attention developed into early adulthood and the OE decreased with age but rarely changed after the 20s. Other studies on impulse control in adults suggested that though age and impulse control were related, the inverse correlation between them were not [24]. These arguments could be supported by our finding that the CE decreased until the 30s and increased after that, but the OE was steady from teen-aged years.

The RT mean sharply decreased until the mid-teenaged years, and then increased slowly in males and females. The RT sd resembled a U-like shape in which the nadir was the mid-20s (Supplementary Fig. 11 in the online-only Data Supplement). The d' was the highest in the late 20s and gradually declined after that (Supplementary Fig. 12 in the online-only Data Supplement). The d' of the other tests in the CAT reached the peaks in the teenaged years to the 20s, which were earlier than that of the SA. According to previous studies, the reaction speed, errors, and accuracy of the sustained attention increased with age [25] and the error-processing brain activation increased continuously into adulthood [26].

DA

The CE of the DA decreased until the mid- to late-teenaged years, and stayed stable after that; however, the OE decreased until the mid-teenaged years and steadily increased from the late-teenaged years and the 20s in males and females (Supplementary Fig. 13 in the online-only Data Supplement). The RT changed to a U-like shape, which decreased until the mid-20s and increased after that. The RT sd also showed a similar tendency, decreasing in the 20s, and then increased rapidly (Supplementary Fig. 14 in the online-only Data Supplement). The d' reached its peak in the 20s and gradually declined after that (Supplementary Fig. 15 in the online-only Data Supplement).

There have been few studies on the divided attention of children and adolescents. In a study of adults, elderly adults (ages 61–80) had a significantly lower level of divided attention capacity in comparison with younger (ages 21–37) and middle-aged (ages 40–58) adults, and the young and middle-aged adults did not differ in the divided attention [27]. A recent study on multitasking found that younger adults performed better than older adults, but the difference in the results was not caused only by age (e.g., development environment familiar with digital machines) [28]. The results of

these previous studies were in accordance with ours.

Spatial working memory test

The graphs of the correct responses in the forward and backward tasks were similar. The correct responses of both males and females increased sharply until the 20s and showed a ceiling effect after that (Supplementary Fig. 16 in the online-only Data Supplement). Both the forward and backward spans quickly climbed in the late teenaged years and 20s, and decreased after that (Supplementary Fig. 17 in the online-only Data Supplement). There have been many studies where working memory has been found to gradually develop throughout childhood and into adolescence. A study on the development of the spatial working memory for the ages 4–15 also reported that linear functions increased with age [29]. However, a study of working memory span for ages 20–70 revealed an age-related reduction in working memory span [30]. The results of the present study were consistent with these results, and it appeared that working memory developed from the mid-teenaged years to the 20s, and then gradually slowed.

There were several limitations to this study. First, there was a lack of representation because the standardization data were collected for children, adolescents, and adults in only Seoul and Gyeong-gi Province. To compensate for that, additional supplementation of people residing in other regions is necessary. Second, the clinical usefulness of the CAT in an adult population has not been confirmed because the clinical study on adult ADHD has not yet been conducted in Korea. Further studies will need to confirm whether the CAT would be useful for screening and diagnosing adults with ADHD.

Nevertheless, this is the first study on how various kinds of attention and working memory change with age from children to adults in Korea. The standardized data from this study could be used to obtain objective attention and working memory data through normal and clinical groups with mental health conditions, including ADHD, in Korea.

CONCLUSION

The study provides the normative data and developmental trajectories on varying types of attention and working memory for children, adolescents, and adults in Korea, from the ages 4–40 through a computerized test tool. The findings will be available in the future for clinical and research material for various clinical groups, including ADHD, as well as for normal populations.

Supplementary Materials

The online-only Data Supplement is available with this article at <https://doi.org/10.5765/jkacap.180033>.

Conflicts of Interest

The authors have no potential conflicts of interest to disclose.

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