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Immense data processing within brain networks in professional gamers

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Abstract

Internet video games represent complex systems that process large data volumes, requiring cognitive skills. We hypothesized that professional gamers must effectively process a vast amount of information to compete, likely involving altered brain functional connectivity (FC), cortical volumes, and white matter connectivity (FA) within ventral attention network (VAN), dorsal attention network (DAN) and thalamocortical networks (TCN). The study recruited 23 professional gamers and 20 healthy control participants. All participants underwent magnetic resonance imaging (MRI) scanning and cognitive function tests. Professional gamers demonstrated increased FC and larger cortical volumes within the VAN, along with improved FA within the DAN compared to controls. Decreased FC within the TCN was also observed. Working memory backward was negatively correlated with the FC from the left thalamus to the left pre-cingulate cortex in all participants. Hence, the brains of professional gamers adapt to respond to an immense influx of external stimuli by enhancing connectivity and cortical volume within the VAN, improving white matter integrity within the DAN, and restricting TCN connectivity.

Keywords: brain functional connectivity; white matter connectivity; dorsal attention network; thalamocortical networks; professional gamers

Introduction

Internet games as a complex and highly engaging activity

Internet video games have evolved into intricate systems characterized by the continuous exchange and processing of large data volumes while acting as complex and engaging activities that demand significant cognitive and neural resources, as evidenced by their impact on cognitive performance and neural processing [1]. The fast-paced nature of gaming environments activates cognitive functions such as attention, working memory, and spatial reasoning, thereby showcasing brain plasticity. Neural circuits related to visual processing and motor coordination are activated during gaming, enhancing problem-solving and hand-eye coordination [1,2]. Despite fostering brain plasticity, prolonged gaming raises concerns about its effects on attention span and impulse control, especially in adolescents [3]. Brain imaging studies revealed cognitive changes in professional gamers and individuals with gaming disorders, highlighting both the benefits and risks of extensive gaming [4].

Professional gamers exhibit extraordinary capabilities in processing external stimuli

Professional gamers, similarly to elite athletes, exhibit exceptional capabilities in processing external stimuli, which are developed through extensive practice and competition. These capabilities stem from advanced cognitive and neural adaptations that enable rapid interpretation and response to dynamic environments with precision [1,3,4,5]. Enhanced attention control, visual-spatial acuity, and decision-making are critical traits distinguishing professional gamers in high-pressure scenarios [5]. Research showed that professional gamers possess superior functional connectivity (FC) in brain regions linked to sensory processing, motor coordination, and executive function, resulting in faster reactions and improved visual attention compared to non-gamers [1,3,4].

These adaptations not only improve gaming performance but also enhance multitasking and rapid information processing skills in non-gaming tasks [2,6]. Professional gamers also demonstrate remarkable attention control and mental discipline, essential for maintaining situational awareness and simultaneously managing multiple variables. Their ability for deep focus and adaptive thinking is linked to enhanced neural plasticity and

cognitive flexibility, which are cultivated through consistent practice and engagement in complex gaming environments [1, 2]. These cognitive traits highlight the unique skill set of professional gamers, offering insights into neural mechanisms underlying their high performance. Consequently, understanding these abilities could provide potential applications in fields requiring similar skills, such as crisis management and strategic planning, showcasing the broader cognitive benefits of structured gaming [7,8].

Data processing within brain networks

Many individuals face the challenge of sensory overload, which is characterized by an abundance of sensory stimuli. Processing large data volumes effectively requires robust neural networks, particularly the dorsal attention network and thalamocortical connectivity.

Studies showed that such increased connectivity enables more efficient allocation of attentional resources, which is crucial for tasks requiring sustained attention and quick decision-making. This is particularly relevant in scenarios involving the rapid processing of large data volumes, such as professional gaming or complex decision-making environments [6,9]. For instance, research indicated that extensive video gaming, demanding significant data processing, is associated with functional changes in brain networks, including the ventral attention network [4]. Furthermore, the relationship between external data processing and ventral attention network connectivity highlights the adaptability of the brain to cognitive demands. This adaptability is evident in various contexts, such as media multitasking [10] and attention capture [11], in which enhanced connectivity in the ventral attention network is observed. Additionally, the ventral attention network is essential for efficiently reallocating attentional resources to quickly respond to novel and important stimuli [12]. These findings suggest potential pathways for targeted training aimed at improving attentional capacities and cognitive performance in demanding environments [13].

The thalamus, a key brain relay station, is crucial for processing sensory information and enhancing sensitivity to external stimuli. The increase in thalamic activity often coincides with a relative suppression of the cingulate gyrus, which is involved in

emotion regulation and internal thought processes. The thalamus plays a significant role in brain-wide information processing, influencing perceptual acuity and responsiveness and facilitating quick reactions to environmental changes [14,15]. During the high activity of the thalamus, the activity of the cingulate gyrus may be reduced; hence, the brain temporarily prioritizes external stimulus processing over introspective and evaluative functions [14,15].

Hypothesis

We hypothesized that professional gamers must effectively process a vast amount of information to compete, likely involving enhanced brain connectivity, increased cortical volumes, and white matter connectivity within the dorsal attention network, compared to controls. Furthermore, the brain connectivity within the thalamocortical network was decreased for effective data processing of the attention network as compared to healthy controls.

Methods

Participants and clinical assessments

Twenty-three professional gamers and twenty healthy controls were recruited at the IT and Human Clinic and Research Center, Chung Ang University Medical Center. All participants were screened using the Structured Clinical Interview for DSM-5. Additionally, they completed psychological scales, including the Beck Depression Inventory (BDI-II) [16], the Dupaul Attention Deficit Hyperactivity Disorder Rating Scale Korean (Dupaul ADHD) [17], and the Young Internet Addiction Scale (YIAS) [18].

Professional gamers of two professional game teams were the members of the League of Legends Champions Korea. The lifestyle and training regimens of South Korean professional gamers have become a topic of interest, particularly in the context of their extensive practice hours. Korean professional gamers generally practice about 10–14 hours daily, which not only involves playing games but also includes strategy meetings, analysis, and team meetings [19].

Age- and education-matched participants who used the Internet and played

Internet games for <2 hours/day and <3 days/week were recruited as healthy controls. In both groups, exclusion criteria comprised (1) impaired behavior or distress due to internet gaming disorder; (2) BDI-II scores >19; (3) other axis I psychiatric disorders, including substance abuse; and (4) head injury or trauma history.

All participants underwent the computerized comprehensive attention test [20]. Of six subsets, only two subsets, including the divided attention and working memory parts, which can impose a high cognitive load, were assessed.

The Chung Ang University Hospital Institutional Review Board approved the study protocol (IRB# 1990-007-386). All participants provided written informed consent. All methods were performed in accordance with the relevant guidelines and regulations.

Brain imaging data processing

All MRI evaluations were performed using the 1.5 Tesla Espree MRI scanner (SIEMENS, Erlangen, Germany). Three different brain imaging types were acquired: 3D T1-weighted magnetization-prepared rapid gradient echo (MPRAGE) as structural MRI (parameters: TR = 1500 ms; TE = 3.00 ms; inversion time = 1100 ms; FOV = 256 × 256 mm; flip angle = 15°; 128 slices; 1.0 × 1.0 × 1.33 mm voxel size), echo-planar 2D blood-oxygen-level dependent (EP2D-BOLD) sequence as resting-state functional MRI (fMRI; parameters: TR=3000 ms; TE = 30.00 ms; 150 time points; FOV = 220 × 185 mm; 64 slices; 3.44 × 5 × 3.44 mm voxel size), and echo-planar 2D diffusion tensor imaging (EP2D-DTI) sequence as diffusion MRI (parameters: TR = 6500 ms; TE = 105 ms; 32 diffusion-weighted directions; FOV = 224 × 224 mm; 41 slices; 1.75 × 1.75 × 3.5 mm voxel size). The pre-processing and analysis of brain images were conducted using MATLAB 2020b (MathWorks, Natick, MA, USA; <https://www.mathworks.com/products/matlab.html>) and NiBabel (<https://nipy.org/nibabel/>), a Python package for neuroimaging data processing.

The structural MRI processing for measuring gray and white matter volume, as well as cortical thickness, was conducted using computational anatomy toolbox (CAT12; <http://www.neuro.uni-jena.de/cat/>), which is an add-on toolbox working with Statistical Parameter Mapping (SPM12; <http://www.fil.ion.ucl.ac.uk/spm/>). All raw images were first

aligned to the same coordinate space, followed by skull stripping. Then, the images were non-linearly registered to the standard MNI space using the DARTEL algorithm and underwent normalization to correct for volumetric distortions. Subsequently, a gyrification surface mesh was reconstructed from the standardized images. To suppress signal noise, a 6-mm full-width at half maximum (FWHM) Gaussian kernel was applied to the segmented white matter, gray matter, and surface mesh. Finally, cortical thickness was extracted from the surface mesh, while the volumes were computed from the segmented gray and white matter. Furthermore, regional values were derived for each image using an appropriate atlas [21,22].

FC was measured using the CONN-fMRI FC toolbox (ver.22.a; www.nitrc.org/projects/conn). All functional images were initially realigned within subjects to correct for head motion, followed by slice-timing correction and co-registration with the corresponding structural image. Then, the structural images were segmented into gray matter, white matter, and cerebrospinal fluid (CSF) compartments, followed by normalization into the standard MNI space via the DARTEL algorithm. Afterward, the functional images underwent spatial smoothing using a 6-mm full-width at half maximum (FWHM). Following spatial pre-processing, temporal denoising was performed using the CONN toolbox default pipeline. Nuisance regressors included the top five principal components extracted from white matter and cerebrospinal fluid signals, six motion parameters and their first-order derivatives, and scrubbing of volumes exceeding a framewise displacement threshold of 0.5 mm. Band-pass filtering (0.008–0.09 Hz) was subsequently applied. Subsequently, Pearson correlation coefficients between the extracted BOLD time series of each region of interest (ROI) and the corresponding ROI-wise signals were calculated as a measure of FC. The resulting coefficients were transformed into Z-scores using Fisher's Z-transformation to ensure the normality of the correlation distribution.

Diffusion MRI analysis was conducted using FSL (<https://fsl.fmrib.ox.ac.uk/fsl/fslwiki>) and MRtrix3 (<https://www.mrtrix.org>). The pre-

processing steps were performed using FSL, beginning with motion correction via linear realignment. Denoising and intensity bias correction were applied to further reduce noise and imaging artifacts. Then, eddy current distortion and subject motion correction were performed using the eddy tool in FSL. This step accounts for eddy-current-induced distortions and movement artifacts, improving the accuracy of diffusion modeling. Afterward, the images were processed to compute fractional anisotropy (FA) maps, representing the directionality of diffusion. Subsequently, fiber orientation distributions (FOD) were estimated using constrained spherical deconvolution (CSD) in MRtrix3. Then, these FODs were then used to generate track-density imaging (TDI) maps and reconstruct white matter fiber tracts for further analysis and visualization. Finally, ROI-wise FA values and tractography for each network were extracted using the XTRACT atlas (<https://fsl.fmrib.ox.ac.uk/fsl/fslwiki/XTRACT>), which provides predefined tract-based ROIs for major white matter pathways.

The dorsal and ventral attention networks for functional connectivity and cortical thickness analyses were defined using the ICA-derived resting-state network templates implemented in the CONN toolbox default ROI sets (Smith et al., 2009). For DTI analysis, white matter tracts were selected from the XTRACT atlas (FSL) based on their anatomical correspondence with the cortical regions comprising these networks. Specifically, the arcuate fasciculus and superior longitudinal fasciculus were selected based on their frontal and parietal projections consistent with the DAN, the inferior longitudinal fasciculus based on its occipito-temporal connectivity relevant to visual processing, and the anterior thalamic radiation based on its thalamo-frontal connectivity relevant to the thalamocortical network.

Statistics

Demographic characteristics, clinical scales, and comprehensive attention test between professional gamers and healthy comparison participants were assessed using an independent t-test. The correlations between clinical scales, FC, cortical thickness, and FA values were assessed using Pearson correlations. A $p < 0.05$ indicated statistical significance. All statistical analyses were conducted using the Statistical Package for the

Social Science (SPSS) version 24 (IBM SPSS statistics). For functional connectivity and FA analyses, multiple comparisons were corrected using the Benjamini-Hochberg false discovery rate (FDR) procedure. Cortical thickness analyses were conducted at an uncorrected threshold of $p < 0.05$.

Results

Comparison of demographic characteristics between professional gamers and controls

There were no statistically significant differences in terms of age, education year, alcohol consumption, and smoking habits between professional gamers and controls. There were no significant differences in BDI scores and Dupaul ADHD scores between the two groups. However, significant differences were observed among the groups in terms of the YIAS scores (Table 1).

Table 1. Comparison of demographic, clinical, and attention characteristics between professional gamers and controls

	Professional gamers (23)	Healthy controls (20)	Statistics
Gender	All man	All man	-
Age (years)	19.2±1.8	18.8±5.3	t=0.35, p=0.73
Handedness	All right- handedness	All right- handedness	-
Education (years)	11.6±2.1	10.7±3.4	t=1.23, p=0.23
Professional experience (years)	2.4±2.5	-	-
Alcohol			
Heavy use	1 (4.3%)	2 (10.0%)	$\chi^2=1.46$, p=0.48
Occasional use	8 (34.8%)	4 (20.0%)	
No use	14 (60.9%)	14 (70.0%)	
Smoking			
Heavy smoker	2 (8.7%)	1 (5.0%)	$\chi^2=0.25$, p=0.88
Occasional smoker	4 (17.4%)	4 (20.0%)	

No use	17 (73.9%)	15 (75.0%)	
Clinical scales			
BDI-II	6.3±4.3	7.6±3.4	t=0.95, p=0.35
Dupaul ADHD	7.4±3.2	6.1±2.6	t=1.39, p=0.17
YIAS	65.3±20.3	39.5±15.4	t=-4.21, p<0.01
Comprehensive attention test			
Divided omission score	5.2±3.7	6.3±5.6	t=-0.75, p=0.46
Divided commission score	2.6±1.3	5.7±4.1	t=-3.45, p<0.01
WM-forward score	9.7±2.3	7.5±1.8	t=3.46, p<0.01
WM-backward score	9.3±2.1	7.3±1.6	t=3.30, p<0.01

BDI-II, Beck Depression Inventory; Dupaul ADHD, Dupaul attention deficit hyperactivity disorder rating scale Korean; YIAS, Young Internet Addiction Scale; WM, working memory

Comparison of functional connectivity within brain networks

Within the ventral attention network, the FC from the right anterior insular to the right anterior cingulate cortex ($B = 0.24$, $p = 0.0012$) and the left anterior insular ($B = 0.24$, $p = 0.0035$) in professional gamers was increased compared to controls (Figure 1).

Within the thalamocortical network, The FC from the right thalamus to the right ($B = -0.26$, $p = 0.0001$) and left pre-cingulate cortices ($B = -0.22$, $p = 0.0005$) in professional gamers decreased compared to controls. The FC from the left thalamus to the right ($B = -0.21$, $p = 0.0008$) and left pre-cingulate cortices ($B = -0.23$, $p = 0.0003$) in professional gamers was decreased compared to controls (Figure 2). However, the FC from the left thalamus to the fight frontal pole in professional gamers was increased compared to control ($B = 0.17$, $p = 0.0008$) (Figure 2).

Figure 1. Functional connectivity within ventral attention network

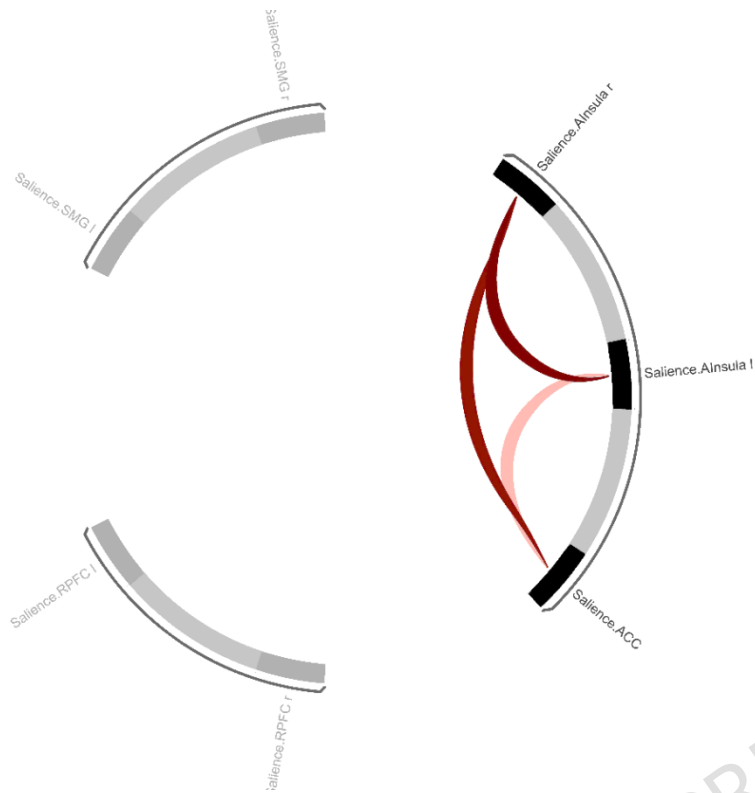
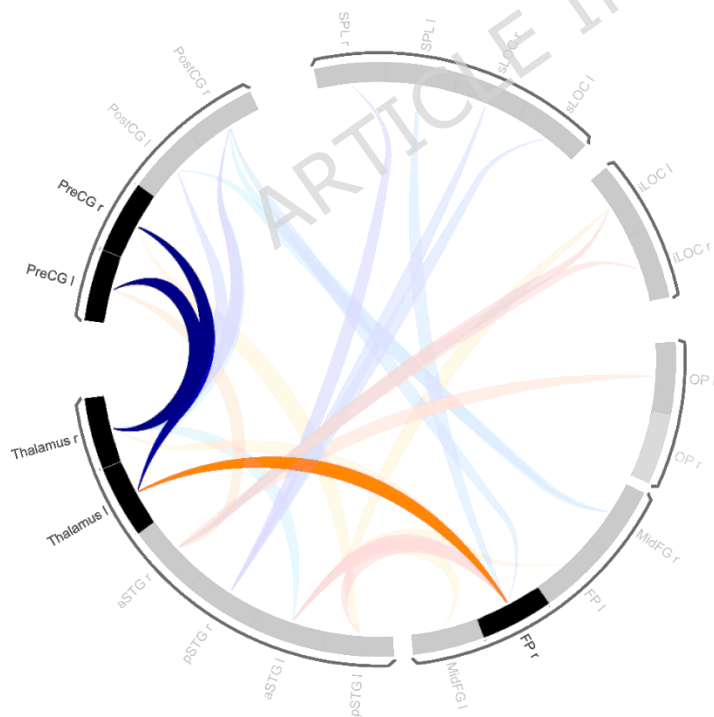


Figure 2. Functional connectivity within thalamocortical network



Comparison of cortical thickness within brain networks

Within the ventral attention network, the cortical thickness within the right anterior insular (AVI, $t = 3.02$, $p = 0.004$) and anterior cingulate (a24, $t = 3.25$, $p = 0.002$; d32, $t = 3.35$, $p = 0.002$) in professional gamers was increased compared to controls.

Comparison of the FA values of DTI within brain networks

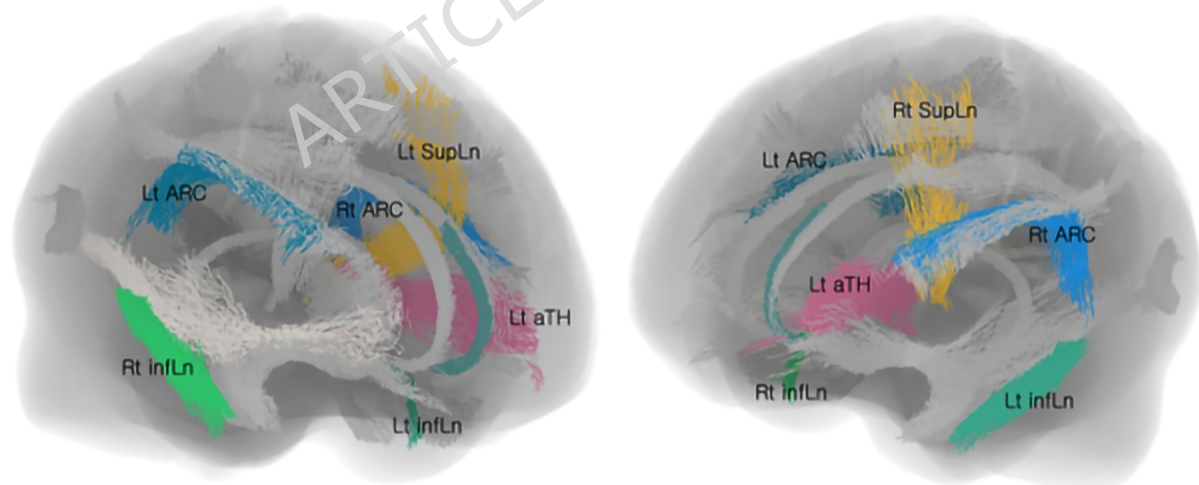
The FA values within both arcuate fasciculi in professional gamers were increased (right $B = 0.007$, $p = 0.01$; left $B = 0.006$, $p = 0.03$) compared to controls.

The FA values within both inferior longitudinal fasciculi in professional gamers were increased (right $B = 0.007$, $p = 0.01$; left $B = 0.006$, $p = 0.03$) compared to controls.

The FA values within both superior longitudinal fasciculi were increased (right $B = 0.008$, $p = 0.03$; left $B = 0.006$, $p = 0.04$) compared to controls.

The FA values within the left anterior thalamic radiation increased ($B = 0.006$, $p = 0.01$) compared to controls. (Figure 3.)

Figure 3. Comparison of fractional anisotropy (FA) values of diffusion tensor imaging within brain networks. White matter tracts showing significantly increased FA values in professional gamers compared to controls are visualized on a 3D rendered brain template. Colors indicate distinct tracts: arcuate fasciculus (blue, Lt ARC; gold, Rt ARC), superior longitudinal fasciculus (blue, Lt SupLn; gold, Rt SupLn), inferior longitudinal fasciculus (green, Lt/Rt infLn), and anterior thalamic radiation (pink, Lt aTH). Left and right hemisphere views are shown separately.

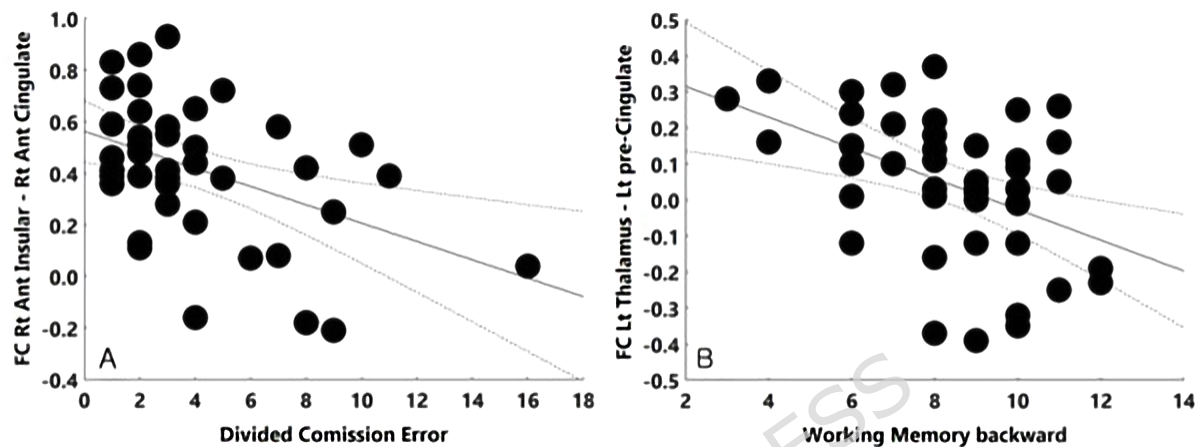


The correlations of clinical scales, functional connectivity, cortical thickness, and FA values

In all participants, there were negative correlations between divided commission errors and the FC from the right anterior insular to the right anterior cingulate cortex ($r =$

-0.436 , $p = 0.003$). In all participants, working memory backward was negatively correlated with the FC from the left thalamus to the left pre-cingulate cortex ($r = -0.451$, $p = 0.003$). (Figure 4.) There was no correlation between other attention scale subscales, the FC, cortical thickness, and FA values of DTI.

Figure 4. The correlations between attention test and functional connectivity



Discussion

The FC within the ventral attention network (from the insular to the anterior cingulate) in professional gamers was increased, while the FC within the thalamocortical network (from the thalamus to the pre-cingulate cortex) in professional gamers was decreased compared to controls. Furthermore, the cortical thickness within the ventral attention network (the insular and the anterior cingulate), as well as the FA values within the arcuate fasciculus, inferior longitudinal fasciculus, anterior longitudinal fasciculus, and thalamic radiation, increased compared to controls.

Altered FC and cortical thickness within the ventral attention and thalamocortical networks in professional gamers

In the current study, the FC within the ventral attention network, as well as the cortical thickness of the ventral attention network, in professional gamers was increased compared to controls. Several studies of professional gamers' brain reported those results in professional gamers [23,24]. Song et al. [24] reported brain activity within the superior and middle frontal gyri in professional gamers. Han et al. [23] reported that professional

gamers showed increased gray matter volume within the cingulate gyrus compared to controls.

These increased brain activities would be associated with the cognitive stimulations of internet games, including visual processing and motor coordination for problem-solving and hand-eye coordination [2]. The ventral attention network, known for its role in detecting and responding to unexpected or salient stimuli, is perfectly suited to handle the dynamic stimuli professional gamers encounter during gameplay. Such stimuli require swift attention shifts and responses, aligning closely with the core functionalities of the ventral attention network [4,25]. Additionally, extensive practice and exposure to gaming environments cause neurological adaptations strengthening the FC of the ventral attention network [4].

For adapting dynamic environments, professional gamers could possess increased FC and cortical thickness within the ventral attention network, which are linked to sensory processing, motor coordination, and executive function, resulting in faster reaction and improved visual attention compared to non-gamers [3,4,26]. In the current study, the FC within the ventral attention network was negatively correlated with divided commission errors. Hyun et al. [26] also declared that increased cortical thickness within prefrontal and parietal cortices was associated with higher performance on the Wisconsin Card Sorting Test. Those results could be associated with the core role of the ventral attention network for efficiently reallocating attentional resources to quickly respond to novel and important stimuli [12].

Interestingly, the FC within the thalamocortical network in professional gamers showed various connectivity changes, compared to controls. In professional gamers, the working memory backward (a complex cognitive task) was negatively correlated with the FC from the left thalamus to the left pre-cingulate cortex.

In current results, the FC from the left thalamus to the right frontal pole in professional gamers was increased compared to control. Increased connectivity between the thalamus and the frontal pole is associated with enhanced cognitive processing abilities in the brain [27]. Thalamic is known to engage in reciprocal connections with the prefrontal

cortex, which includes the frontal pole, playing a vital role in cognitive control and decision-making tasks [27,28]. Increasing the connectivity of the thalamo-cortical region to process large amounts of data seems like a reasonable outcome.

However, an interesting finding in current result is that thalamo-cingulate connectivity decreases. In response to huge amounts of cognitive stimuli, the thalamus and cingulate would reflect a trade-off, meaning that the thalamus was highly activated during the reduced activity within the cingulate gyrus [29,30,31,32]. The heightened activity of the thalamus during intense cognitive tasks reflects its critical role in facilitating communication within broader neural networks, which are vital for maintaining consciousness and cognitive function [29,31]. In contrast, the cingulate gyrus, particularly the anterior cingulate cortex, is integral to emotional regulation and cognitive control [30]. Research indicated that the cingulate gyrus can adapt its activity based on current cognitive demands. For instance, during overwhelming stimuli, its activity may reduce — a shift potentially indicating that resources are being redirected to more immediate processing needs via other neural structures, such as the thalamus and prefrontal cortex [32].

Increased FA values of DTI within the white matter

Increased FA values within the white matter in the current study may be associated with effective control of the large volume of visual process stimuli, sustained attention, strategic planning, and problem-solving abilities [33,34,35,36,37,38,39]. The arcuate fasciculus is a major pathway connecting the frontal and temporal lobes. Furthermore, through the interaction of these regions, it supports complex cognitive functions, such as working memory [38]. The inferior longitudinal fasciculus connects the occipital and temporal lobes and is integral to the visual processing and integration of cognitive functions [34,36]. The inferior longitudinal fasciculus is crucial for the integration of visual information with other cognitive processes [36]. Therefore, improved microstructural integrity of the inferior longitudinal fasciculus, which is indicated by increased FA values, can translate to faster and more efficient processing of visual inputs, consequently

supporting enhanced cognitive focus and concentration [34].

The superior longitudinal fasciculus connects the frontal, parietal, and occipital lobes, integrating regions critical to attention, executive function, and working memory — all of which are essential for executive set shifting and attentional control, which are essential for concentration [37]. Increased FA values within the superior longitudinal fasciculus would be associated with the enhanced capacity to concentrate, particularly during tasks requiring sustained focus and rapid task-switching [39]. Increased FA values in the anterior thalamic radiation can contribute to enhanced cognitive capacities, including processing speed and executive functioning [33]. These improvements might manifest as better strategic planning and problem-solving abilities [35].

Resting-state functional connectivity as an intrinsic neural framework

Several interpretive considerations should be noted. Although resting-state functional connectivity is well-established as a marker of stable, trait-like network organization, it does not directly capture the dynamic, state-dependent neural processes that unfold during active gameplay. Accordingly, the present findings should be understood as reflecting the intrinsic neural framework that may underlie the cognitive capabilities of professional gamers, rather than as a direct measurement of real-time processing such as rapid attention switching during competitive play. Future work integrating ecologically valid task-based paradigms with resting-state measurements will be needed to more precisely link this trait-like architecture to the dynamic cognitive demands of professional gaming.

Limitations

There were several limitations in the current study. First, the current results could not obtain a sufficient sample size to be applied to all professional gamers or individuals who frequently play games. However, the analysis targeting professional gamers with >2 years of experience registered in the Korean professional gaming league is considered to have purity and specificity in subject selections. Additionally, general cognitive intelligence was not assessed in the present sample. Working memory performance as measured by the

CAT may therefore be partially confounded by individual differences in baseline intellectual capacity. Future studies should include standardized intelligence assessments to allow more precise interpretation of domain-specific cognitive differences between professional gamers and controls.

Second, the current brain analysis results were based on resting-state fMRI, which reflects intrinsic network organization rather than dynamic neural responses during actual gameplay. Future research could benefit from employing functional near-infrared spectroscopy (fNIRS), which allows for neuroimaging during active task performance, including real gaming environments, thereby providing a more ecologically valid assessment of neural changes associated with professional gaming expertise. Furthermore, cortical thickness, as a structural measure, reflects long-term morphological adaptation rather than neurodynamic changes, and is therefore qualitatively distinct from functional imaging measures such as fMRI or fNIRS. In addition, cortical thickness analyses in the present study were conducted without correction for multiple comparisons, which may increase the risk of false-positive findings. Results from the cortical thickness analysis should therefore be interpreted with caution pending replication.

Third, all neuroimaging data were acquired using a 1.5T MRI scanner with anisotropic voxel dimensions, which may have introduced partial volume effects and limited spatial precision relative to higher-field systems. Although all images underwent manual quality control inspection prior to analysis, this hardware constraint cannot be fully corrected post hoc. Future studies should consider replication using 3T or higher-field scanners with isotropic voxel acquisition. Additionally, the resting-state fMRI data were acquired with a TR of 3000 ms, which limits temporal resolution and may increase susceptibility to aliasing of high-frequency physiological noise. The 7.5-minute scan duration (150 volumes) exceeds the recommended minimum for reliable resting-state connectivity estimation, partially compensating for the lower sampling rate. Band-pass filtering was applied to further attenuate physiological noise contributions.

Conclusions

The current study analyzed brain changes in response to the large amounts of data processing using various brain assessment modules. The brains of professional gamers adapt to respond to an immense influx of external stimuli by enhancing rapid visual information processing, high concentration, strategic planning, and effective problem-solving abilities. To achieve this, neurotransmission in the white matter regions related to concentration increases, along with enhanced connectivity and volume of the attention network. Additionally, in the thalamocortical network, connectivity with the cingulate is restricted, facilitating the efficient processing of cognitive information rather than emotional information.

Data availability

The data analysed during the current study are not publicly available due to the Personal Information Protection Act and Bioethics and Safety Act of South Korea, which strictly prohibit the external sharing of medical data to protect patient privacy. However, data are available from the corresponding author upon reasonable request and subject to ethical approval and data use agreements.

Author Contributions

G.C. performed the data analysis and inspection. Y.S. researched and developed the analysis methodology. D.H. wrote the manuscript and provided overall supervision of the study. All authors have read and agreed to the published version of the manuscript.

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