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Increased Cortical Thickness in Professional On-Line Gamers

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Objective The bulk of recent studies have tested whether video games change the brain in terms of activity and cortical volume. However, such studies are limited by several factors including cross-sectional comparisons, co-morbidity, and short-term follow-up periods. In the present study, we hypothesized that cognitive flexibility and the volume of brain cortex would be correlated with the career length of on-line pro-gamers.

Methods High-resolution magnetic resonance scans were acquired in twenty-three pro-gamers recruited from StarCraft pro-game teams. We measured cortical thickness in each individual using FreeSurfer and the cortical thickness was correlated with the career length and the performance of the pro-gamers.

Results Career length was positively correlated with cortical thickness in three brain regions: right superior frontal gyrus, right superior parietal gyrus, and right precentral gyrus. Additionally, increased cortical thickness in the prefrontal cortex was correlated with winning rates of the pro-game league. Increased cortical thickness in the prefrontal and parietal cortices was also associated with higher performance of Wisconsin Card Sorting Test.

Conclusion Our results suggest that in individuals without pathologic conditions, regular, long-term playing of on-line games is associated with volume changes in the prefrontal and parietal cortices, which are associated with cognitive flexibility.

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Key Words On-line game, Cortical thickness, Frontal cortex, Cognitive flexibility.

INTRODUCTION

Recent studies have examined whether video games change the brain in terms of activity and cortical volumes.[1-3] Erickson et al.[1] have reported that dorsal striatal volume predicts the level of accomplishment achieved in video games in healthy volunteers. Hubert-Wallander et al.[2] and Lee et al.[3] have also suggested that visual attention training using video games leads to improvement in brain activation of prefrontal cortex and visuo-spatial attention in individuals with playing game. Further, Zhou et al.[4] have reported that adolescents with internet addictions have less gray matter volume in the cingulate gyrus compared to healthy controls. However, there are several limitations in interpreting these results including comorbidity in the samples, ambiguous playing game time (How much time and duration), and genre of game.

As reported in our previous study,[5] pro-gamers may be a type of sample that closely parallels the characteristics of patients with an on-line gaming addiction. Pro-gamers typically play on-line games for over 10 hours/day, similar to those with an on-line gaming addiction. However, pro-gamers do not show any addiction symptoms such as a disrupted daily life structure and sleep-wake cycle, high impulsivity, or other comorbidities. Pro-gamers appear to be unique subjects that show brain changes in response to long-term, on-line game play without underlying comorbidities. In one voxel-based morphometry study,[5] pro-gamers versus general on-line game users show increased brain volume in the prefrontal cortex. Among various on-line games, StarCraft is a well-known, real-time strategy games that is thought to require much executive functioning and spatial attention for complex visual targets.[5,6] With the specific group of pro-gamers (Regular, long-term playing

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unified genre of on-line games in individuals without pathologic conditions), we hypothesized that cortical volume of the brain and cognitive flexibility would be correlated with the career length of pro-gamers.

METHODS

Subjects and measurements

Twenty-three pro-gamers (all male and mean age=19.8±1.7 years) from two StarCraft pro-game teams were assessed at Chung Ang University Medical Center. All pro-gamers were members of the Korea eSports Association (KeSPA). Exclusion criteria were: 1) disrupted behaviors or distress due to excessive on-line game play, 2) Beck Depression Inventory scores >19, 3) other axis I psychiatric disorders including attention deficit hyperactivity disorder, major depressive disorder, and substance abuse, and 4) history of head injury or trauma. No pro-gamers met any of the exclusion criteria.

All pro-gamers were screened with the Structured Clinical Interview for DSM-IV and the Beck Depression Inventory (BDI).[7] The impulsiveness of pro-gamers was assessed using the Barratt Impulsiveness Scale-Korean version (BIS-K).[8,9] Additionally, a psychiatrist (D.H.H) interviewed all pro-gamers to rule out other psychiatric disorders. The protocol used in the current study was approved by the Institutional Review Board at Chung Ang University Hospital. Written informed consent was provided by all pro-gamers.

Executive function involving cognitive flexibility was estimated with a computerized version of the Wisconsin Card Sorting Test (WCST) (CNT4.0, Maxmedica Inc).[10] The cards in WCST contained colored shapes considering one of three possible rules (color, shape, and number). If the chosen sorting rule was correct, pro-gamers observed the feedback "correct" for a placed card. After several correct trials, the sorting rule abruptly changes without notice. Thus, pro-gamers received the feedback information "wrong" for changing their response for choosing a relevant sort in next trial. Scores are recorded along several dimensions, with the number of categories achieved (TCC), the number of total errors (TE) and the number of perseverative errors (PE) committed the most commonly measured category.

The education level of the pro-gamers was 12.0±0.8 years. The average career length of the pro-gamers was 4.0±1.9 years. Seventeen pro-gamers graduated from high school or university. Three pro-gamers were student gamers with the permission of chairman in school, which is similar to a student athlete. Three pro-gamers quit high school to become a pro-gamer with the consent of parents. Pro-gamers played StarCraft an average of 9.2±1.6 hours/day and used the Internet (except for game playing) an average of 1.8±0.9 hours/day. The mean Young Internet Addiction Scale Score (YIAS) score of pro-gamers was 40.9±13.5. The mean BDI score of pro-gamers was 7.2±4.9. The mean total BIS-K score was 50.2±5.7.

MR imaging processing and data analysis

All MR imaging was performed on a 1.5 Tesla Espree MRI scanner (SIEMENS, Erlangen, Germany). 3D T1-weighted magnetization-prepared rapid gradient echo (MPRAGE) data were collected with the following 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. Cortical thickness was measured using FreeSurfer 5.1 (http://surfer.nmr.mgh.harvard.edu). The standard protocol of the package uses intensity normalization, white matter segmentation, tessellation of the gray/white matter junction, inflation of the folded surface with correction of topological defect, and the measurement of the cortical thickness as defined by the distance between the grey-white matter junction and the pial surface. All images were aligned to 1-mm isotropic stereotaxic standard space (Montreal Neurological Institute, MNI 305 template) and smoothed with a Gaussian kernel of 15 mm full-width at half maximum (FWHM).

Statistical analysis

For each hemisphere, a general linear model estimated the effects of career length as pro-gamer on cortical thickness. The statistical analysis was done on the surface data that included vertices and their Cartesian coordinates. The ages of the subjects were included as covariates of no interest. Results represented by log of p were mapped onto the average brain and considered significant at uncorrected $p<0.005$ with a cluster extent threshold of 50 mm^2. Partial correlations between career length of pro-gamer and total/sub-scale scores of Wisconsin Card sorting Test were analyzed with Pearson correlations, controlling for age. For all statistical analyses, the α level for significance was set at 0.01 (0.05/5) and all analyses were performed using Statistica 6.0.

RESULTS

Career length was positively correlated with cortical thickness in three brain regions: right superior frontal gyrus [Talairach coordinates: 8.7, 36.9, 40.1; maxima=3.2 log of p value; size (mm^2)=292.1], right superior parietal gyrus (27.1, -56.0, 62.6; 3.1 log of p value; 137.23), and right precentral gyrus (40.9, -7.5, 57.6; 2.7 log of p value; 50.2) (Figures 1 and 2). Controlling for age, cortical thickness in the right superior frontal gyrus was positively correlated with rate of winning in the Korea StarCraft pro-game league (r=0.51, p=0.02). There was no significant correlation between cortical thickness of other ar-

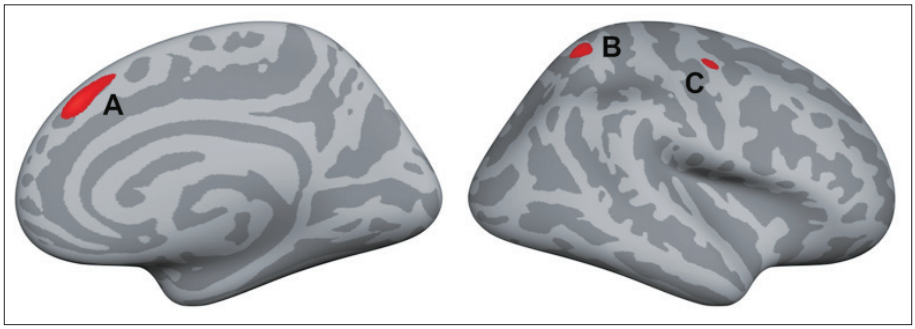

Figure 1. Brain regions which was associated with career length of the pro-gamers. A: Right superior frontal gyrus [Talairach coordinates: 8.7, 36.9, 40.1; maxima: 3.17 (log of p); cluster size: 292.1 (mm^2)]. B: Right superior parietal gyrus [Talairach coordinates: 27.1, -56.0, 62.6; maxima: 3.1 (log of p); cluster size: 137.23 (mm^2)]. C: Right precentral gyrus [Talairach coordinates: 40.9, -7.5, 57.6; maxima: 2.7 (log of p); cluster size: 50.2 (mm^2)].

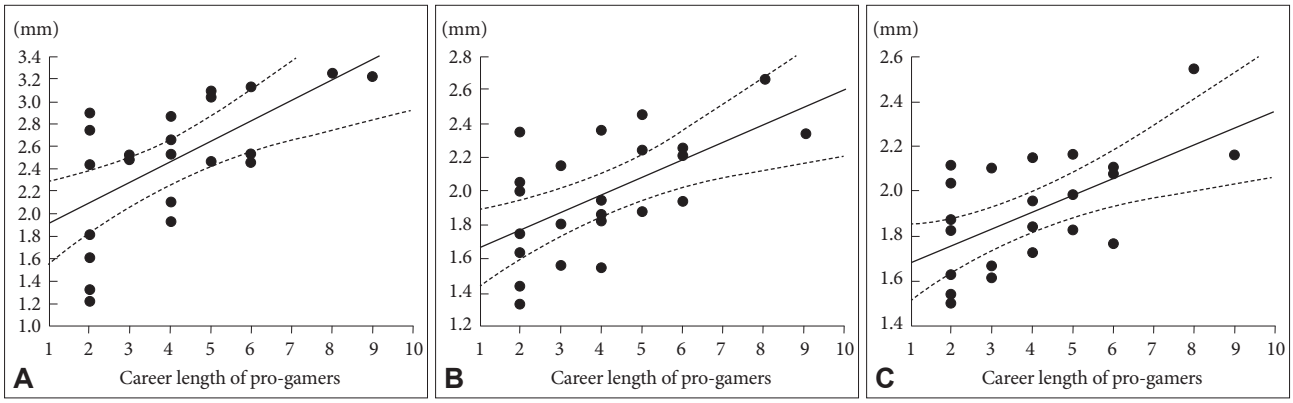

Figure 2. The correlation between cortical thickness and career length of the pro-gamers. A: Right superior frontal gyrus, r=0.57, p<0.01. B: Right superior parietal gyrus, r=0.67, p<0.01. C: Right precentral gyrus, r=0.63, p<0.01.

eas and winning rate. Controlling for age, career length was negatively correlated with total trials needed to complete six categories (TCC) (r=-0.58, p<0.01) and total number of errors (TE) (r=-0.44, p<0.01) of WCST. Controlling for age, cortical thickness in the right superior frontal gyrus was negatively correlated with TCC (r=-0.64, p<0.01), TE (r=-0.64, p<0.01) and PE (r=-0.59, p<0.01). Controlling for age, cortical thickness in the right superior parietal gyrus was also negatively correlated with TCC (r=-0.59, p<0.01) and TE (r=-0.56, p<0.01). There was no significant correlation between cortical thickness in the precentral gyrus and any subscale of the WCST.

DISCUSSION

The current research examined the unique subject group of StarCraft pro-gamers. As mentioned before, pro-gamers in current research have played same game 10 hours/day, about four years. However, they have no pathologic conditions. StarCraft on-line game requires executive and spatial cognitive functions. Putting those results of several studies together, current research may contribute to the argument of the effect of on-line game on the brain change.

We found that the career length of pro-gamers was associated with increased cortical volume in the frontal cortex, parietal cortex, and precentral gyrus. In addition, increased volume in the prefrontal cortex was positively correlated with the rate of winning. Increased volume in the prefrontal and parietal cortices was also positively associated with higher functioning as assessed by the WCST.

The right medial superior frontal cortex was thicker in the pro-gamers with longer career length and higher winning rate. This cortical region is known to be involved in attention shifting,[11] executive function,[12] or inhibitory control of action,[13] which are all contributing to cognitive flexibility necessary for playing on-line games. Recent studies have reported that video game training changes activation in the dorsolateral prefrontal gyrus and improves cognitive flexibility.[2,3] In an fMRI study, Lee et al.[3] reported that game training produced less activation in the dorsolateral prefrontal cortex with greater performance improvement in visuo-spatial attention and goal-directed motor planning. Hubert-Wallander et al.[2] reported that action-based video games can improve selective attention and spatial distribution of vision. First-person shooter game players also show superior cognitive flexibility relative to individuals with little or no video game playing experience.[14] Bonilha et al.[15] reported that decreased gray matter

volume in the prefrontal cortex is associated with difficulties set-shifting and mental inflexibility in patients with schizophrenia. Decreased cortical thickness in the right medial superior frontal gyrus was found in the patients with attention deficit hyperactivity disorder and it was correlated with severity of inattention and impulsivity.[16] In our study, increased volume of prefrontal cortex was associated with career length of pro-gamers. Moreover, the increased volume was correlated with a higher winning rate and better cognitive flexibility (lower TCC and TE). We cautiously suggest that long-term, on-line game playing can increase cortical volume in the prefrontal cortex and associated cognitive functioning.

In addition to the prefrontal cortex, we also found that the parietal cortex was associated with career length and cognitive functioning (lower TCC and TE). The parietal cortex is part of the brain network that controls movement and is also thought to be associated with the spatial attention required for processing complex visual targets.[17] The posterior parietal cortex is thought to be associated with processing execution and preparation signals.[18] Moreover, those signals may reflect behavior shifting induced by internal and external trigger.[18] The superior parietal cortex is implicated in working memory representations assessed with the WCST.[19] Interestingly, the left hand utilized often during StarCraft game playing. In response to error mismatch during right/left hand presentation experiments, unexpected left hand stimulation provoked activation in the right superior parietal cortex.[20] Increased volume of right parietal cortex may reflect the trained left hand of StarCraft pro-gamers. The increased cortical thickness in the right precentral gyrus could be viewed in the same context. The plasticity of cortical gray matter volume has been reported after motor practices[21,22] and also after practices on visual-spatial tasks[23] including playing video-games.[18,19] In our study, increased gray matter volume of prefrontal, parietal and prefrontal cortices was associated with career length of pro-gamers. Moreover, the increased volume in the prefrontal and parietal cortices was correlated with a higher winning rate and better cognitive flexibility. We cautiously suggest that long-term, on-line game playing can increase cortical volume in the prefrontal and parietal cortices and associated cognitive functioning.

There were several limitations in the current study. First, because pro-gamers are a very specific group, readers should be cautious in generalizing these results to other types of on-line gamers. In future study, more characteristics of pro-gamers such as personality and coping style should be assessed.

Second, because the current study has no control group, research design is strict enough to show meaningful correlation. A more informative study including other comparison groups should be done in the future.

Conclusively, regular long-term playing of on-line games of individuals without pathologic conditions may change brain volume in the prefrontal and parietal cortices, which are associated with cognitive flexibility.

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