BRAIN CONNECTIVITY
Volume 00, Number 00, 2022

DOI: 10.1089/brain.2021.0193

Enhanced Dorsal Attention Network to Salience Network Interaction in Video Gamers During Sensorimotor Decision-Making Tasks

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Abstract

Introduction: Video game playing is most often a perceptually and cognitively engaging activity. Players enter into sensory-rich competitive environments, which require them to go from trivial tasks to making active decisions repeatedly and could lend themselves to improve sensorimotor decision-making capabilities. Since video game playing requires moment-to-moment switching of attention from one aspect of sensory information and task to another, enhanced attention control and attention-switching mechanism in the brain can be thought as the neural basis for such improvements. Previous studies have suggested that attention switching is mediated by the salience network (SN). However, how SN interacts with the dorsal attention network (DAN) in active decision-making tasks and whether video game playing modulates these networks remain to be investigated.
Methods: Using a modified version of the left–right moving dot motion task in a functional magnetic resonance imaging experiment, we examined the decision response times (dRTs) and functional interactions within and between SN and DAN for video game players (VGPs) and nonvideo game players (NVGPs).
Results: We found that VGPs had lower response times for all task conditions and higher decision accuracy for a medium speed setting of moving dots. Associated with this improved task performance in VGPs compared with NVGPs was an increase in DAN to SN connectivity. This SN-DAN connectivity was negatively correlated with dRT.
Discussion: These results suggest that enhanced influence of DAN over SN is the brain basis for improved sensorimotor decision-making performance as a result of engaging long term in cognitively challenging and attention-demanding activities such as video game playing.

Keywords: decision-making tasks; directed functional connectivity; fMRI; Granger causality; salience network; video game playing

Impact Statement

Being able to flexibly direct attention is a key factor in sensorimotor decision-making. Video game playing, an attentionally and cognitively engaging activity, can have a beneficial effect on attention and decision-making. Through this study, we examined whether video game players (VGPs) have improved decision-making skills and investigated the brain basis for improvements in a functional magnetic resonance imaging experiment.

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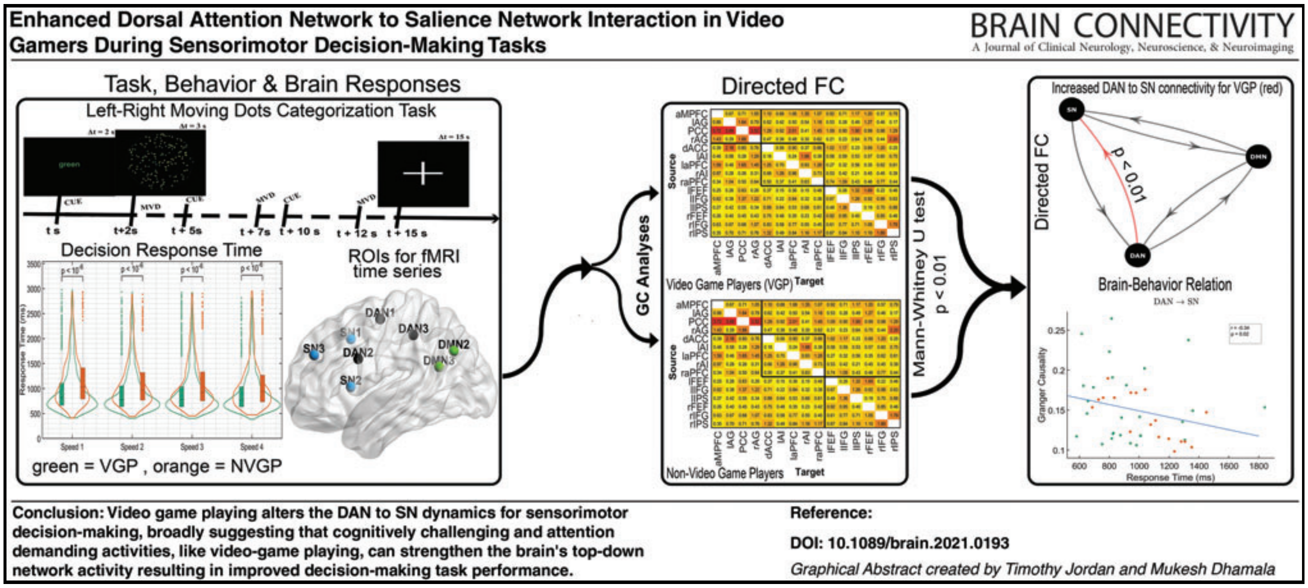


Brain connectivity from dorsal attention network regions to salience network regions was higher in VGPs and negatively correlated with decision response time for both groups. These results suggest that video game playing can enhance the top–down interaction to improve sensorimotor decision-making.

Introduction

Decision-making tasks occur every day at sporadic moments. To quickly decide and properly respond to these tasks, attention must be flexible in switching from rest to task and from one aspect of the task to another. Only once attention gets switched and focused onto the task, relevant sensory information gets integrated and a sensorimotor decision is formed. This process of attention switching is a key step to allocate cognitive resources in decision-making and is thought to be mediated by three networks: the salience network (SN), default mode network (DMN), and dorsal attention network (DAN) (Zhou et al, 2017).

The process of attention switching is a part of decision-making (Cooper et al, 2014; Rangelov and Mattingley, 2020; Yang, 2017). Without it, the time in which a decision needs to be made could pass. The complexity and allowed time of a decision can challenge a person to arrive at a correct answer. Therefore, the more time they have for integrating information and less time for switching attention, the better.

The desire to increase our ability to switch attention and make quick decisions while maintaining accuracy pushes us to find ways of training our attention-switching and decision-making capabilities. One potential activity to train these processes is video game playing. Within the span of one game, players must make hundreds of choices in the moment, weighing the pros and cons of each choice and how the answer will help them achieve victory.

Previous studies have shown that video game playing can lead to improved and increased attention control (Granek et al, 2010; Green and Bavelier, 2015; Wu and Spence, 2013), improved task switching (Basak et al, 2008; Oei and Patterson, 2014), and increased visual information processing (Dye et al, 2009; Green and Bavelier, 2007; Green and Bavelier, 2003; Powers et al, 2013).

These increases in cognitive capabilities are processes that involve the SN. The SN plays key mediating roles in attention switching (Zhou et al, 2017), decision-making (Chand and Dhamala, 2016a; Chand and Dhamala, 2016b; Goulden et al, 2014), and stimulus processing and response (Lamichhane et al, 2016; Menon and Uddin, 2010). This role of SN leads us to the idea that observed behavioral differences between video game players (VGPs) and nonvideo game players (NVGPs) will be due to changes in connectivity between SN and the other networks.

In this functional magnetic resonance imaging (fMRI) study, we examined how video game playing affects decision response times (dRTs) and accuracy and brain network interactions within and between SN and DAN during active sensorimotor decision-making tasks. We defined regions of interest (ROIs), extracted fMRI time series, and computed undirected connectivity and directed connectivity using Granger causality (GC) techniques (Chand and Dhamala, 2016a; Dhamala et al, 2008b). Based on previous findings of SN mediating the attention-switching process (Zhou et al, 2017), we hypothesized that video game playing would modulate the connectivity of SN with other networks.

Materials and Methods

Participants

Forty-seven people in total (VGPs: 28 [4 females], aged 20.64 ± 2.45 years, and NVGPs: 19 [12 females], aged 19.94 ± 2.62 years) participated in this study. Participants were recruited by posting flyers physically and digitally on approved areas at Georgia State University and neighboring universities in the Atlanta area and by advertising on regional video game group Facebook pages. Each participant filled out a questionnaire about their video game playing to determine which group a person would be placed in, following similar criteria used in the study by Green and Bavelier (2007) and other previous studies (Gao et al, 2018; Stewart et al, 2020).

We used a minimum of 5 h per week of video game playing in the last 1 year as a cutoff time for a participant to be categorized as a VGP. This requirement is similar to the one established in a previous behavioral study by Green and Bavelier, in which 5 h per week for at least 6 months was the requirement. Participants who indicated playing over 5 h per week in one of four types of video game genres for the last 2 years were considered to be VGPs.

The four types of VGPs we recruited were those playing one of the following games: First-Person Shooter (FPS), Real-Time Strategy (RTS), Multiplayer Online Battle Arena (MOBA), and Battle Royale (BR). NVGPs averaged less than 30 min of playtime per week, and short bursts of playing games were not considered significant as training studies have shown that repeated playing is required to gain skills or habits from playing.

All participants were required to pass the full Ishihara test for color deficiency (Clark, 1924). Participants provided signed written consent forms and underwent health screening before their scheduled scan session. Participants were compensated for their participation in the experiment. The Institutional Review Boards of Georgia State University and Georgia Institute of Technology, Atlanta, Georgia, approved this study.

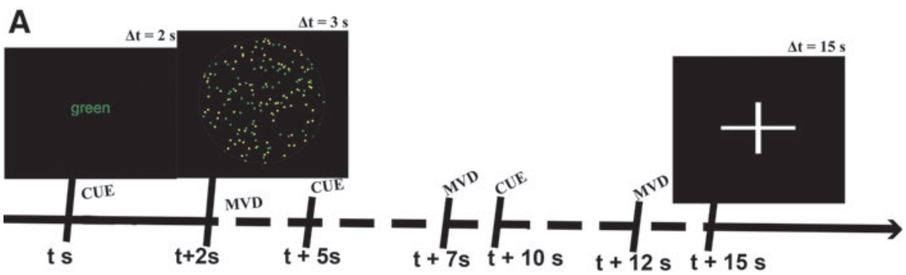
Stimuli

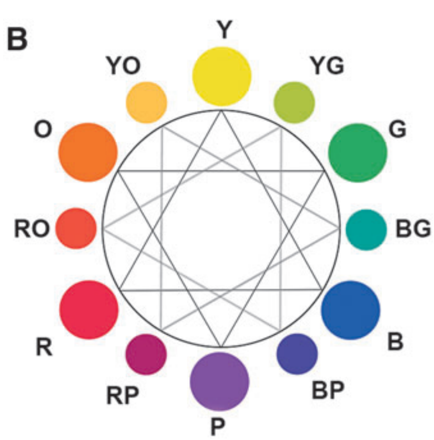
The decision-making task for this experiment was a moving dot (MD) left–right categorization task, as shown in Figure 1. It was modified from a commonly used version (Chand and Dhamala, 2016a). The original moving dot task uses random motion of dots of the exact same color as the interfering pattern, while here we utilized a set of moving dots going in the opposite direction and with varying degree of contrast to the target dot set. Participants would be cued for a color to attend to on the next screen. The cue was a text prompt that spelled out the color, and the font color was of the same color to avoid confusion.

On the next screen, participants would see two different sets of overlapping dots (each set consisting of 600 dots) going in opposite directions. Participants would then respond whether they thought the dots of the cued color were going left or right using a controller inside the fMRI. The direction of the cued set was randomized between each MD task, and the colors of the two sets were randomly picked from a list of preset groupings.

These difficulty pairings were based on the color wheel. The difficulty levels were as follows: easy, between two primary colors; medium, between primary and adjacent secondary colors; and hard, a primary or secondary color versus an adjacent tertiary color. The speed setting went from 0 (no-motion) to 4, the fastest setting. These settings were determined by finding the max speed of the dots before illusory motion reversal became possible and using points every quarter of the max speed for lower speed settings.

For each task period, the difficulty and speed settings of the task were randomly chosen for that period. Within each task period, participants would respond to a total of 3 MD tasks totaling 15 sec. To respond, participants would indicate if the dots were moving left, right, or not at all by pressing the left or right button with their thumbs or no button press at all if no-motion. After the task period, there was a rest period of 15 sec before the next task period began with new difficulty and speed settings.





Difficulty Level	Color Pairing
Easy	R-B, R-Y, B-Y
Medium	R-O. R-P, B-P, B-G, Y-O, Y-G
Hard	R-RO, R-RP, Y-YO, Y-YG, B-BP, B-BG, O-R O-YO, P-RP, P-BP, G-YG, G-BG

FIG. 1. Organization of task time line and how difficulty levels are determined. **(A)** The time line that the task followed. Each task period was 15 sec, containing three MVD stimuli, followed by 15 sec of rest. Each task period was randomly assigned a difficulty level and speed setting for all three MVD stimuli inside that period. **(B)** The color wheel to determine the difficulty level. The easy difficulty level was assigned for primary versus primary color; medium difficulty level was assigned for primary versus adjacent secondary color; and hard difficulty level was assigned for primary or secondary versus adjacent tertiary color. MVD, moving dots.

Figure 1 shows the experiment design with event sequence and timings. Each combination of speed and difficulty settings appeared four times for each participant in each scan session for a total of 60 task periods. All scan sessions followed the same design. The task sequence was designed and displayed using the PsychoPy stimulus software (Peirce et al, 2019).

Experiment design

Before their scheduled MRI scan session, participants were shown a demonstration of the task they would be completing, and all questions pertaining to the task were answered. Participants were told to respond as quickly and accurately as possible for which direction they thought the colored set of dots they had been cued for were going.

Participants were informed of the total time of the scan session and safety protocols and given an emergency button to reduce anxiety inside the fMRI scanner. Participants were asked to lie still without moving during the scan periods. All motion movements were monitored during scan sessions, and participants were notified if they began to move too much.

Data collection and analysis

Behavioral data. Behavioral data were collected using the stimulus software, PsychoPy (Peirce et al, 2019), and the computer running the software. Participants' decisions through button presses and response times (RTs) were recorded for each MD task in the scanner. Decision response was recorded as correct if the participant indicated the correct direction that the prompted dots were going in through button press, otherwise a wrong button press or no button press was considered incorrect.

RTs were taken as the time from MD onset after the text cue. Participants had to respond within 3 sec of MD onset. The Bonferroni correction method was used to control for false positives due to multiple comparisons in statistical tests involving the behavioral data.

fMRI data. Whole-brain structural and fMRI was conducted on a 3 Tesla Siemens Magnetom Prisma MRI scanner at the joint Georgia State University and Georgia Institute of Technology Center for Advanced Brain Imaging, Atlanta, Georgia.

First, high-resolution anatomical images were acquired for anatomical reference using a T1-MEMPRAGE scan sequence (repetition time (TR) = 2530 ms, echo time (TE) = 1–4: 1.69–7.27 ms, inversion time = 1260 ms, flip angle = 7°, and voxel size 1 × 1 × 1 mm). Four functional scans were acquired using a T2*-weighted gradient echo-planar imaging sequence (TR = 535 ms; TE = 30 ms; flip angle = 46°; field of view = 240 mm; voxel size = 3.8 × 3.8 × 4 mm; number of slices = 32, collected in an interleaved order; and slice thickness = 4 mm). Each scan run was 7 min and 30 sec long, for a total functional scan time of 30 min, translating into 3440 brain images.

Second, all fMRI data were preprocessed using the Statistical Parametric Mapping MATLAB software suite (Friston, 2010). Data were first imported from the Digital Imaging and Communications in Medicine format into Neuroimaging Informatics Technology Initiative, then slice-time corrected, realigned for motion correction using the middle image and multiple regressors, and realigned for field distortion using fieldmap corrections. Each participant's functional data were then coregistered to their anatomical image. The anatomical image was then segmented and normalized to a Montreal Neurological Institute template. The normalization parameters were then applied to the functional data.

Finally, the normalized data were spatially smoothed with an 8-mm isotropic Gaussian kernel. No participants' data were excluded due to excessive movements in the scanner. No other denoising steps were applied during preprocessing and no masks were applied.

Brain ROI. We selected the ROIs for this study based on a previous study by Zhou et al (2017) on network interactions for attention switching. Briefly, Zhou et al (2017) defined the attention-switching networks as follows: the DMN consisting of four nodes: posterior cingulate cortex, left and right angular gyri, and anterior medial prefrontal cortex; the SN consisting of five nodes: left and right anterior insulas (aIs), left and right anterior prefrontal cortices, and dorsal anterior cingulate cortex (dACC); and the DAN with six nodes: left and right frontal eye fields (FEFs), left and right inferior frontal gyri, and left and right inferior parietal sulci (IPSs).

Table 1 shows the center coordinates of each ROI and which network it belongs to. Figure 2 shows the ROI used. Time series were extracted from each ROI using 6-mm spherical masks created with the MarsBaR software package (Brett et al, 2002).

Undirected functional connectivity analyses. Region- and task condition-specific fMRI time series segments were normalized, voxel averaged, and corrected for linear trends. Region-to-region undirected functional connectivity (FC)

Table 1. Regions of Interest as Network Nodes

ROI	*MNI coordinates x, y, z (mm)*	*Network*
aMPFC	3, 54, 18	DMN
lAG	−48, −69, 33	DMN
PCC	−3, −57, 21	DMN
rAG	51, −63, 27	DMN
lFEF	−24, −9, 57	DAN
lIFG	−51, 9, 27	DAN
lIPS	−42, 36, 45	DAN
rFEF	27, −3, 54	DAN
rIFG	54, 12, 30	DAN
rIPS	39, −42, 51	DAN
dACC	−3, 15, 42	SN
lAI	−36, 15, 6	SN
laPFC	−27, 45, 30	SN
rAI	33, 18, 6	SN
raPFC	30, 42, 30	SN

All ROI spheres were based on previous studies (Zhou et al, 2017).

aMPFC, anterior medial prefrontal cortex; dACC, dorsal anterior cingulate cortex; DAN, dorsal attention network; DMN, default mode network; lAG, left angular gyrus; lAI, left anterior insula; laPFC, left anterior prefrontal cortex; lFEF, left frontal eye field; lIFG, left inferior frontal gyrus; lIPS, left inferior parietal sulcus; MNI, Montreal Neurological Institute; PCC, posterior cingulate cortex; rAG, right angular gyrus; rAI, right anterior insula; raPFC, right anterior prefrontal cortex; rFEF, right frontal eye field; rIFG, right inferior frontal gyrus; rIPS, right inferior parietal sulcus; ROI, region of interest; SN, salience network.

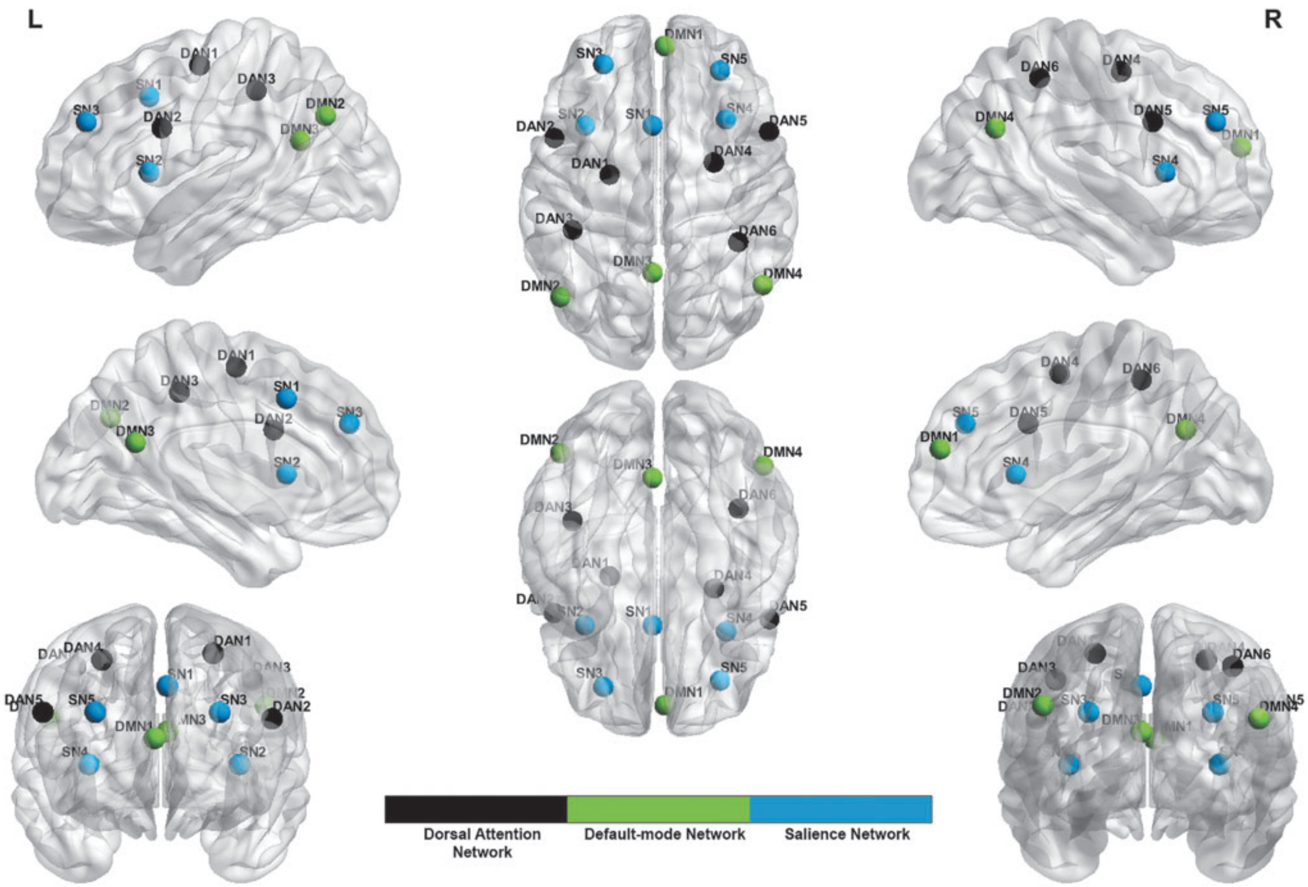


FIG. 2. Regions of interest. ROIs were drawn on the regions of three networks known to be involved in attention switching based on previous studies (Zhou et al, 2017). The three networks are the DAN (marked in black), SN (marked in blue), and DMN (marked in green). These nodes were used for time series extraction and directed functional connectivity analyses. DAN, dorsal attention network; DMN, default mode network; ROIs, regions of interest; SN, salience network.

was calculated for each participant by pairwise Pearson correlation coefficient. FC values from regions in one network to another network for each participant were combined to obtain a between-network correlation array, that is, all connections from DMN to SN per participant combined.

The Fisher transformation (Fisher, 1915) was applied to each FC value inside the array to obtain the network-to-network Fisher *z*-array. Utilizing a *t*-test, group differences were determined between group Fisher *z*-arrays for each network–network pairing. The Bonferroni correction method was used to control for false positives due to multiple comparisons in statistical tests on FC values.

Directed FC analyses. For the GC analysis, all participants' preprocessed time series data were then combined as trials to calculate the proper model order in parametric modeling for GC calculations. Once the model order was determined, GC matrices were computed for each participant using GC methods (Dhamala et al, 2008a; Dhamala et al, 2008b). GC from region 2 to region 1 in the frequency domain is defined as follows:

$$I_{2\to1}(f)=\ln\left(\frac{S_{11}(f)}{S_{11}(f)-\left(\Sigma_{22}-\frac{\Sigma_{12}^2}{\Sigma_{11}}\right)|H_{12}(f)|^2}\right)$$

where $\sum$ and H are the elements of noise covariance and transfer function matrices, respectively, in the bivariate autoregressive model (Dhamala et al, 2008a; Dhamala et al, 2008b).

The frequency band-specific or time-domain equivalent GC is as follows:

$$F_{2\to1}=\frac{1}{f_2-f_1}\int_{f_1}^{f_2} I_{2\to1}(f)df$$

where $f_1=0.05\ Hz$ and $f_2=0.9\ Hz$. The sampling rate was $1.87\ Hz=TR^{-1}$, where TR is the MR repetition time in the functional runs. The GC threshold for statistical significance was computed by using the random permutation technique (Blair and Karniski, 1993; Brovelli et al, 2004) under the null model of no statistical interdependence with 200 random permutation samples.

The significance of group differences was determined by using the Mann–Whitney *U*-test (McKnight and Najab, 2010). The Bonferroni correction method was used to control for false positives due to multiple comparisons in statistical tests on GC values.

Brain–behavior correlation. Undirected and directed FC values for each participant per connection were plotted

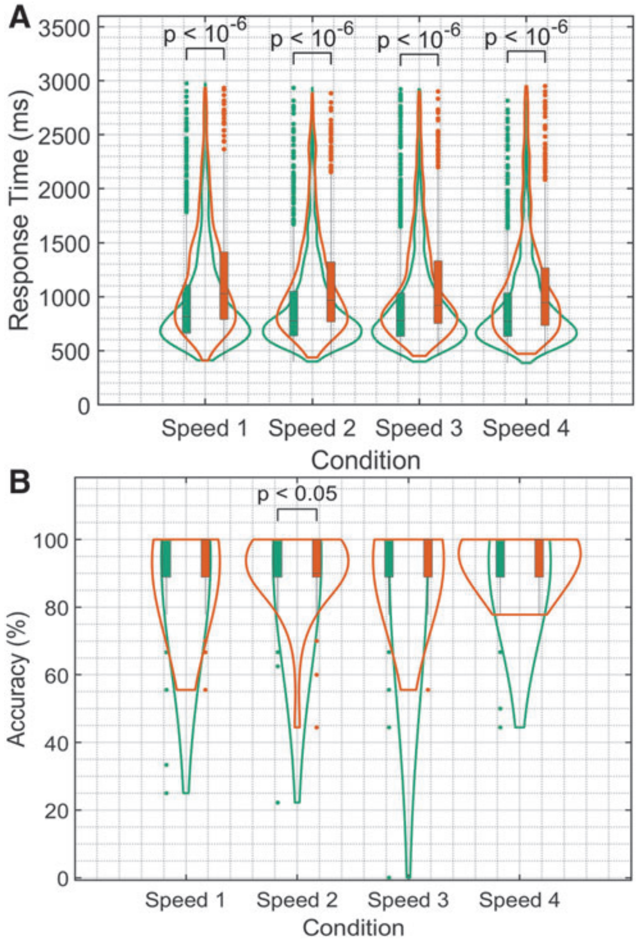


FIG. 3. Behavioral performance. Behavioral response time and accuracy results for both VGPs (green) and NVGPs (orange) by speed setting conditions. **(A)** VGPs have decreased response time for all speed settings compared with NVGPs. All comparisons are significant at Bonferroni-corrected $p < 10^{-6}$. **(B)** VGPs have higher mean accuracy scores compared with NVGPs. Only accuracy scores for the speed 2 setting are significantly different at uncorrected $p < 0.05$. NVGP, nonvideo game player; VGP, video game player.

against dRT to assess correlation between RT and connectivity. Spearman's rank correlation coefficient thresholded at $p < 0.05$ was used to establish the significance of correlation between GC and RT.

Results

Behavioral response

The RT, the time from MD onset to participant response (max of 3 sec), was collected for each participant and compared based on the speed setting using a *t*-test. Decision accuracy was calculated for each participant based on the number of correct responses. The total number of correct responses divided by the total number of decision tasks determined each participant's accuracy score. Accuracy scores were compared using a *t*-test.

Only speed setting 2 was found to have a significant difference between groups, with VGPs having higher accuracy scores (VGP = 94 ± 9, NVGP = 90 ± 10, $p = 0.044$, uncorrected for multiple comparisons). RTs showed that both groups decreased their RTs as the dots moved faster.

From *t*-tests, we see that VGPs had significantly faster RTs for all speed settings compared with NVGPs, $p < 10^{-6}$; speed 1 (VGP = 959 ± 456 ms, NVG P= 1171 ± 493 ms, $p < 1.28*10^{-18}$), speed 2 (VGP = 922 ± 427 ms, NVGP = 1107 ± 479 ms, $p < 9.56*10^{-16}$), speed 3 (VGP = 918 ± 441 ms, NVG P= 1093 ± 491 ms, $p < 1.35*10^{-21}$), and speed 4 (VGP =904 ± 407 ms, NVGP = 1093 ± 499 ms, $p < 1.77*10^{-19}$).

Figure 3 and Table 2 show all results for behavioral task performance by speed setting. Due to the speed 2 setting showing significant differences between VGPs and NVGPs for both accuracy and RT, only this setting's RT was used for all following analyses.

Brain network interaction

Undirected FC *z*-score values from each region in one network to regions in another network for each participant were combined for each group to make a group connection array from network 1 to network 2, that is, DMN to SN. Group network connectivity matrices were compared using a *t*-test. We found that for both overall task and speed setting 2, all three network-to-network connections were significantly different at Bonferroni-corrected $p < 0.01$ between groups, as shown in Figure 4.

TABLE 2. BEHAVIORAL RESPONSE (MEAN ± STANDARD DEVIATION): DECISION ACCURACY (%) AND RESPONSE TIME (MS) FOR ALL SPEED SETTINGS

Condition	*Behavioral measure*	*VGP (mean ± SD) ms*	*N_1*	*NVGP (mean ± SD) ms*	*N_2*	*p*
Speed 1	Accuracy	92.94 ± 12.07	124	91.8 ± 10.7	71	0.51
	RT	959.1 ± 456.53	1130	1171.82 ± 492.91	773	1.35×10^{-21}
Speed 2	Accuracy	93.59 ± 10.72	124	90 ± 11.81	71	0.03
	RT	922.33 ± 426.98	1148	1107.68 ± 479.04	779	1.28×10^{-18}
Speed 3	Accuracy	92.48 ± 13.15	124	93.18 ± 8.68	71	0.69
	RT	918.43 ± 441.24	1146	1093.07 ± 491.55	767	9.56×10^{-16}
Speed 4	Accuracy	92.5 ± 10.08	124	93.75 ± 7.85	71	0.37
	RT	904.48 ± 407.16	1145	1093.29 ± 499.5	788	1.77×10^{-19}

N_1 and N_2 are sample sizes, which come from the number of times that the records were pooled together to compute the accuracy of tasks and number of recorded decision response times of all trials excluding some incomplete responses in four functional runs from all participants in each group.

NVGP, nonvideo game player; RT, response time; SD, standard deviation; VGP, video game player.

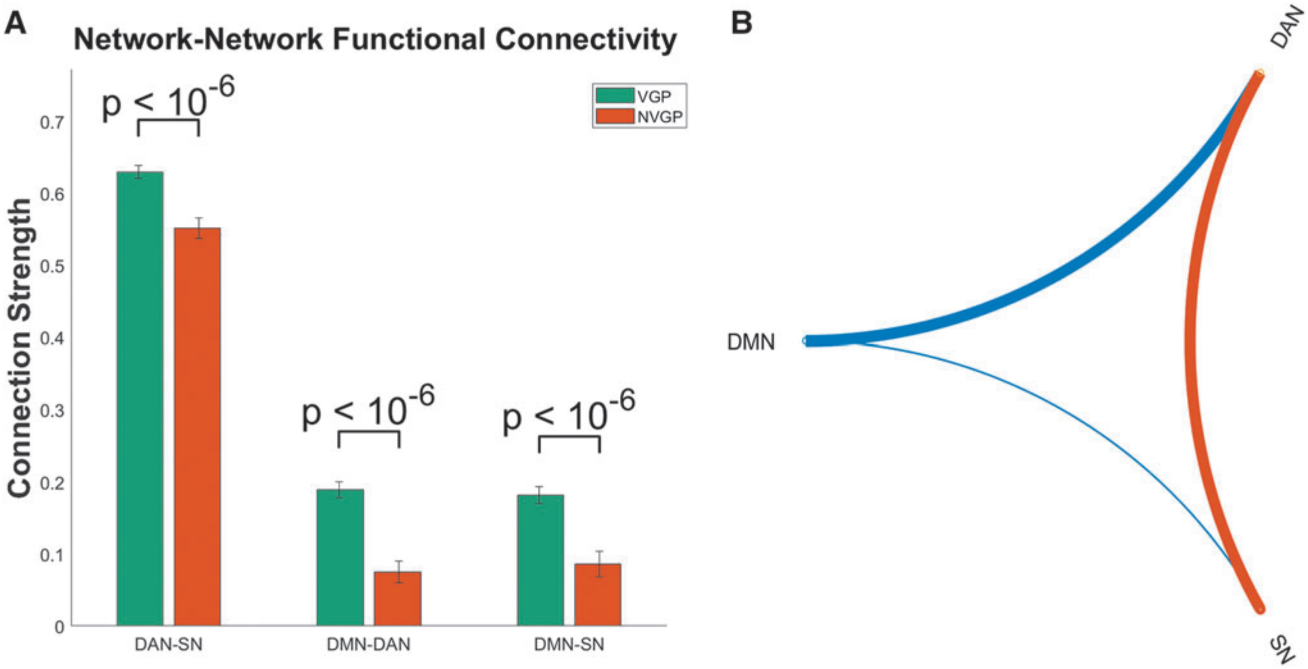


FIG. 4. Undirected functional connectivity. Undirected functional connectivity values that are significantly different between VGPs and NVGPs. **(A)** Network–network connections in descending order. **(B)** All displayed edges are significantly different at $p < 10^{-6}$ between VGPs and NVGPs. Line thickness is weighted on how significantly different the connections are, that is, the more significant the difference, the thicker the line displayed.

VGPs were found to have higher connectivity between all networks compared with NVGPs; DMN-SN (overall: $p < 1.73{*}10^{-5}$, speed 2: $p < 1.72{*}10^{-5}$), DMN-DAN (overall: $p < 1.29{*}10^{-12}$, speed 2: $p < 8.28{*}10^{-10}$), and DAN-SN (overall: $p < 3.59{*}10^{-9}$, speed 2: $p < 5.89{*}10^{-8}$).

GC values were first put through a permutation test against the null hypothesis of no interdependence in the data and then Mann–Whitney *U*-test for group comparisons. GC values were compared similar to undirected FC values, but with added separation for network-to-network connections based on directionality. We found one of six connections to be significantly different at Bonferroni-corrected $p < 0.05$ between VGPs and NVGPs for overall task comparison and speed setting 2. VGPs had increased connectivity to SN from DAN (overall: $p = 0.0009$, speed 2: $p = 0.004$).

The asterisk mark in Figure 5A shows the individual connections that were significantly elevated at uncorrected significance p of 0.001. Figure 5B shows the connections considered between networks, with connections that were significantly enhanced in VGPs displayed in red.

Brain–behavior correlation

Significant GC values were correlated with RT to show how the brain response related to behavioral performance. We found that for both overall performance and speed setting 2 performance versus connectivity, there was a significant moderate negative correlation for DAN to SN, as shown in Figure 6. Connectivity to RT correlation was higher for speed setting 2 ($r = -0.34$, $p = 0.02$) than overall performance ($r = -0.296$, $p = 0.048$).

Although undirected FC values for DAN-SN were seen tending toward being significant ($p = 0.11$), no significant correlations were found between undirected FC values and RT.

Discussion

In this study, we examined a group of network interactions that control the cognitive process of attention switching for decision-making tasks. We found that VGPs were quicker to respond for all conditions. VGPs were more or equally accurate, but only significantly more accurate for speed setting 2. This difference could be due to video game playing only making VGPs more proficient at speeds up to speed setting 2 and not higher speeds, meaning that those settings were also difficult for VGPs.

This also shows that VGPs have increased decision-making performance by primarily being able to respond more quickly. Previous studies have found that the SN mediated the process of attention switching (Zhou et al, 2017). Examining these network interactions in our study, we first found that VGPs had increased undirected FC between SN and DAN.

Expanding upon this analysis, we used the GC analysis and saw that VGPs had increased influence from DAN to SN. The pairwise directed connectivity values that are significantly greater in video gamers indicate that this increase from DAN to SN is primarily driven by three directions: from left FEF to dACC, right IPS to dACC, and left IPS to left aI. These increases in connectivity were found to correlate with both overall task performance and speed setting 2. This connectivity was negatively correlated with RT.

Additionally, we saw that for the speed setting 2, where we observed increases in both speed and accuracy, the correlation of DAN to SN with RT was higher for this setting compared with the overall measure of behavioral performance. This result indicates that connectivity to SN from DAN is a key factor in creating the task performance differences between those with video game playing experience and those

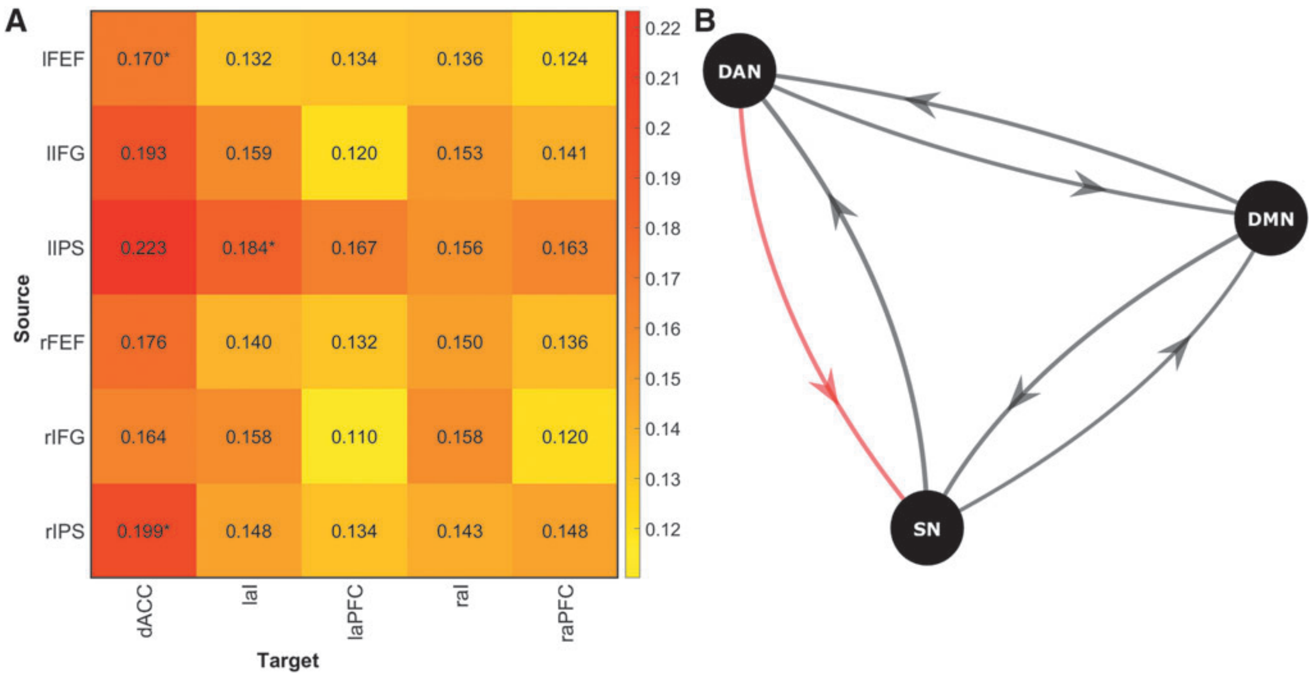


FIG. 5. Directed functional connectivity in VGPs. **(A)** The connectivity matrix in VGPs compared with NVGPs (* significantly different values at uncorrected $p < 0.001$). **(B)** The network-to-network directed connectivity (shown in red) is significantly increased in VGPs compared with NVGPs at Bonferroni-corrected $p < 0.05$. The rest of the network-to-network directions are not significantly different between groups (shown in black). dACC, dorsal anterior cingulate cortex; lAI, left anterior insula; laPFC, left anterior prefrontal cortex; lFEF, left frontal eye field; lIFG, left inferior frontal gyrus; lIPS, left inferior parietal sulcus; rAI, right anterior insula; raPFC, right anterior prefrontal cortex; rFEF, right frontal eye field; rIFG, right inferior frontal gyrus; rIPS, right inferior parietal sulcus.

without. Previous studies have shown VGPs to have increased attention control (Granek et al, 2010; Green and Bavelier, 2015; Wu and Spence, 2013). Our results showing DAN influencing SN agree with these previous findings.

The DAN is involved with voluntary top–down control of attention for goal-oriented tasks (Astafiev et al, 2003; Corbetta and Shulman, 2002; Corbetta et al, 2000, 2005; Giesbrecht et al, 2003; Hopfinger et al, 2000; Kastner et al, 1999; Shulman et al, 2003; Shulman et al, 1999). More specifically, studies have shown its involvement in task-focused working memory encoding and preplanning attention guidance (Majerus et al, 2018; Rajan et al, 2021), controlling information processing by filtering out behaviorally irrelevant input to enhance sensorimotor processing (Wen et al, 2012), visual search processing for tasks involving interference (Ossandon et al, 2012), and modulating activity between multiple networks (Chand et al, 2018).

The findings in previous studies have also shown that DAN's modulatory functions are crucial in healthy individuals and reduced in conditions involving cognitive impairment (Bokde et al, 2010; Chand et al, 2018). Due to participants receiving a prompt for which dots to attend to, we believe this is the cause of the observed increase in DAN's causal influence on SN.

Increases in DAN's causal influence on SN correlating with increased behavioral performance indicate that DAN is potentially being utilized for salience attention control to focus attention on the area where the dots will appear and then remain focused and process the motion of the dots they were prompted for. Top–down control of attention would allow for increased RT due to the participant becoming more quickly task-focused and processing task-relevant information more efficiently.

This study has several potential limitations. First, we did not have a gender-balanced sample size to perform a comparative analysis by gender in brain and behavioral responses. Thus, future studies should examine the effects of video game playing across males and females.

Second, although our groups were recruited from university campuses and at similar education levels, we did not explicitly screen for education level and no cognitive assessments were conducted to determine the levels for cognitive skills. Therefore, no correlations could be drawn between cognitive levels and task performance.

Third, the task used in this study required a simple button press motor response and we therefore made the assumption that the times for motor response alone were not different across groups. Future studies can use event-related designs in fMRI and also in electroencephalography or magnetoencephalography experiments to separate out the times for perceptual decision-making alone.

Fourth, the gamer participants recruited in this study had played four action video games: FPS, RTS, MOBA, and BR.

How the findings of the enhanced brain network activity and behavior from the current study generalize beyond these action video games needs further research. While Wu and Spence (2013) found improvements in visual search tasks by training in shooting and driving games, Basak et al (2008) reported significant improvements in many executive control functions, including task switching, short-term

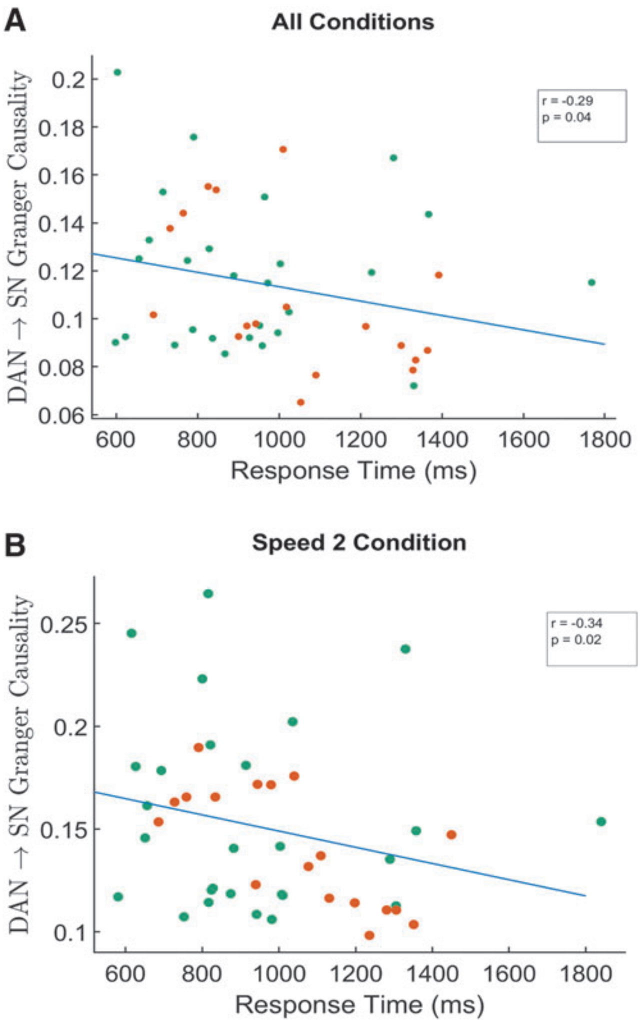


FIG. 6. Brain–behavior correlation: GC versus RT. Scatter plot of significant functional connections that correlated with task performance. VGP points are in green and NVGP points are in orange. Plots compared network-to-network GC with response times. Correlation coefficients (*r*) and *p*-values are displayed in the top right of each plot. **(A)** Brain–behavior correlation for overall connectivity versus overall RT. **(B)** Brain–behavior correlation for speed setting 2 connectivity versus RT. GC, Granger causality; RT, response time.

memory, and visuospatial attention, but only improvement trends in inhibition and reasoning, by RTS video game playing.

Thus, future studies should go beyond the action games we used, examine if different types of video games have different effects, and determine what features of games are essential for transferable beneficial effects on various aspects of cognition and behavior.

Conclusions

In this study, we found that video game playing alters the DAN to the SN dynamics for sensorimotor decision-making. The improvements in behavioral performance due to video game playing could stem from an increase in the top–down control of attention, as reflected in the increased connectivity from the DAN to SN and its correlation with the dRT.

This would mean that VGPs are able to better control the object that they deem as important and control their attention to focus more solely on that object, thus resolving it more quickly for the response. These results also broadly suggest that cognitively challenging and attention-demanding activities, such as video game playing, can strengthen the brain's top–down network activity, resulting in improved decision-making task performance.

Authors' Contributions

T.J. contributed to conceptualization, methodology, software, formal analysis, and writing—original draft, review, and editing. M.D. contributed to conceptualization, methodology, software, supervision, funding acquisition, and writing—original draft, review, and editing.

Author Disclosure Statement

No competing financial interests exist.

Funding Information

This work was funded by two internal grant awards from the Brains and Behavior Program and the Center for Advanced Brain Imaging to M.D.

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