Functional Connectivity of the Default Mode Network in Participants with Higher versus Lower Creativity Scores

A Bachelor Thesis

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Abstract

Creativity is defined in the literature as the proficiency to produce novel and useful outcomes, and thus the terminology ‘divergent thinking’ has been chosen to represent the construct creativity. The goal of this study was to gain more knowledge on this topic because of the deficiency in knowledge of creativity due to the varying previous findings. This study aimed to take a closer look on the functional connectivity of the inferior parietal lobule (IPL), medial prefrontal gyrus (mPFC) and posterior cingulate cortex (PCC), which are the major nodes of the default mode network, in participants with higher versus lower creativity scores. It was hypothesized that participants with higher scores on the CAQ would show an increased functional connectivity in the brain regions linked to divergent thinking than participants with a lower score on the CAQ. From 75 participants from the N&C protocol of the ‘MPI-Leipzig Mind-Brain-Body’ dataset, the participants who scored the lowest 33% and highest 33% on the CAQ were compared in terms of functional connectivity. Functional connectivity has been established using data from resting-state functional MRI (rs-fMRI). Whilst a foregoing empirical study found stronger functional connectivity in higher creative participants between the PCC and mPFC, this thesis could not find any significant functional connectivity. The unexpected discovery of insignificant results may lend credence to the idea that divergent thinking requires both controlled and spontaneous cognitive processes rather than just the former.

Keywords: Default mode network (DMN), creativity, divergent thinking, creative achievement questionnaire (CAQ), functional connectivity, resting state fMRI study, inferior parietal lobule (IPL), medial prefrontal gyrus (mPFC), posterior cingulate cortex (PCC).

Introduction

Art is often the first thing that comes to mind when we think of creativity. Art has a very long history and can be seen as a human evolution like language (Contreras-Vidal et al., 2019). Nowadays, visual art is applied to psychotherapies for its beneficial outcomes. While traditional approaches such as medicine and education fall short in some cases, art therapy can be beneficial instead. Especially among military service members suffering from post-traumatic stress disorder and children dealing with developmental and behavioral problems is the creative self-expression method, encouraged in art therapy, gainful (Contreras-Vidal et al., 2019).

But creativity is ubiquitous and does not stop to just visual art and art therapy. Creativity can be found in various domains such as science, culinary arts and even in the workspace (Contreras-Vidal et al., 2019). Creativity is everywhere in our daily life, but little do we know about its neuronal underpinnings.

Creativity is a comprehensive concept without a generalized construct. The creative ability, a higher cognitive function, can be described as the proficiency to yield novel and useful outcomes (Ishiguro et al., 2022; Sun et al., 2022; Wigert et al., 2022) meaning that the outcomes should be original and valuable (Ishiguro et al., 2022). Other research attempts to make a description of the concept creativity by the distinction of convergent and divergent thinking. Wherein convergent thinking can be conceptualized as following a sequence of certain steps with the goal to find a solution to a problem. While on the contrary, divergent thinking is the exploration of as much as possible unique solutions to a problem (Zagonari & Giacomoni, 2022). Sunavsky & Poppenk (2020) made such distinguishment due to the conviction of convergent thinking being more a predictor of intelligence rather than a predictor of creativity. It has been shown in the research of Ishiguro et al. (2022) that divergent thinking is positively correlated with, inter alia, creative achievement and thus the Creative Achievement Questionnaire (CAQ) predicts divergent thinking. Although the concept creativity is multi-dimensional, researchers largely use divergent thinking as the main component to conceptualize creativity and thus divergent thinking is considered as one of the hallmarks of creativity.

In the literature, many differing opinions on the subject of divergent thinking exist. Numerous studies have been conducted in an effort to comprehend divergent thinking. But little do we know about the neural underpinnings of creativity.

To unveil the neural impact of creativity on the brain, mostly structural magnetic resonance imaging (MRI) and functional magnetic resonance imaging (fMRI) has been used. Both imaging techniques share the same physical background, they both rely on the principle of nuclear magnetic resonance (NMR) but they differ in outcome. Whereas structural MRI is used to image the anatomy of the brain (Op de Beeck & Nakatani, 2019a), fMRI is used to indirectly measure brain activity through observing the fluctuations in blood-oxygen level dependent (BOLD). In this thesis the resting-state fMRI (rs-fMRI) method is chosen to reveal the brain regions who tend to be more active during the absence of stimuli. When two or more brain regions display similar BOLD fluctuations at the same time, they are likely working towards the same objective. The degree of interaction between these various brain regions is referred to as functional connectivity (Op de Beeck & Nakatani, 2019b).

Due to the examination voxel-based morphometry, research done by the usage of structural MRI, Li et al. (2015) found smaller regional grey matter density in the right medial prefrontal gyrus (mPFC) and right inferior parietal lobule (IPL) in researchers with a high academic achievement. This reduction in the anatomical volume of these areas may be indicative to fostering creativity in the field of research and scientific discoveries. In other words, seeking innovation and hypothetical thinking is correlated with lower cortical density in the mPFC and the IPL. However, a strong correlation between creative achievement and grey matter volumetry has been found in the prefrontal cortex (PFC), including the ventromedial prefrontal cortex (vmPFC), in the study of Chen et al. (2014). Meanwhile, results in the research of Fink et al. (2014) affirm an enhanced grey matter density in the right precuneus in subjects with high verbal creativity. Which may indicate the vivid imaginative ability of creative persons.

The brain regions found in structural neuroimaging, which commonly referred to divergent thinking, also overlap the default mode network. The default mode network (DMN), one of the resting brain state connectivity, is known as a network that connects a set of brain regions; The medial prefrontal cortex (mPFC), the posterior cingulate cortex (PCC) and the adjacent precuneus, and bilateral inferior parietal lobes are the major nodes of DMN (Beaty et al., 2014; Sunavsky & Poppenk, 2020). Furthermore, the default mode network is associated with spontaneous cognition, internally directed attention (Beaty et al., 2014; Shofty et al., 2021) and goal directed tasks (Sunavsky & Poppenk, 2020). A previous study has constituted that this network model predicts creative achievement (Anderson et al., 2022) and thus the construct divergent thinking. The activation in the default network is consistently high when participants are in a resting state, which occurs when there is an absence of stimuli or external task demands. The activity in the DMN decreases during focused attention on the external world (Beaty et al., 2014; Shofty et al., 2021; Sunavsky & Poppenk, 2020). This hallmark of the DMN gives us the ability to research the functional connectivity in resting brain state.

Furthermore, it is not only possible to examine the anatomy of the brain regions involved in divergent thinking. It is also attainable to extend the research by examining the occurring patterns of activation in the connection between the concerning brain regions.

In a previous functional imaging study by Beaty et al. (2014) is, in resting brain state, the differences between high- and low-divergent thinking subjects examined. Results in this study revealed an increased connectivity between the inferior frontal gyrus (IFG) and the regions of the DMN within subjects with a higher level of creativity. Being more specific, ROI-to-ROI analysis revealed significantly stronger connectivity within subjects with a higher divergent thinking ability between the left IFG and the left PCC, the left IFG and bilateral IPL, and finally left IFG and mPFC. In addition, the right IFG showed a significantly stronger connection between the bilateral IPL (Beaty et al., 2014). This suggests that the left IFG is significantly stronger connected to all the DMN regions than in subject with reduced capacity of divergent thinking.

Since the regions of IFG are commonly related to cognitive control and the nodes of DMN higher associated with spontaneous (Beaty et al., 2014), it is possible to suggest that the ability to devise creative ideas involves spontaneous and controlled cognition processes.

Consolidating the aforegoing findings, the brain regions found in functional and structural fMRI research affirm that creativity is remarkably associated with the connections between IFG and DMN. It is chosen to exclude IFG in this paper, because it is frequently associated with the executive control network (ECN) (Hu et al., 2019; Sunavsky & Poppenk, 2020). Although a co-activation pattern has been found between ECN and DMN in previous research (Chen et al., 2023), the ECN relies on conscious control processes, such as evaluation and selection of ideas (Anderson et al., 2022), rather than spontaneous cognition processes (Chen et al., 2023; Sunavsky & Poppenk, 2020).

The present study aims to take a closer look on the functional connectivity solely on these specific nodes of the default mode network: IPL left, IPL right, mPFC and PCC (precuneus).

Moreover, in this paper, the terminology ‘divergent thinking’ has been chosen to represent the construct of creativity. To measure this construct, the creative achievement questionnaire (CAQ) has been used to make a distinguishment between higher creative participants and lower creative participants. As mentioned before, this questionnaire aims to measure an individual’s creative achievement which predicts divergent thinking (Ishiguro et al., 2022).

This study is needed because of the deficiency in knowledge about how the functional connectivity of DMN functions within healthy participants with a higher creativity achievement than other participants. Previous studies tried to reveal the anatomical differences between these groups by using structural neuroimaging. Furthermore, researchers discovered the cooperation of DMN and IFG, or ECN, by using functional connectivity neuroimaging. The present study could help us better understand solely the functional connectivity of DMN within higher creative persons.

The central question of this study is: is there a difference in functional connectivity in the DMN between people with higher creative achievement scores and people with lower creative achievement scores? It is hypothesized that participants with higher scores on the CAQ, higher creative participants, will show an increased functional connectivity in the brain regions linked to divergent thinking –IPL left, IPL right, mPFC and PCC– than participants with a lower score on the CAQ, lower creative participants.

Methods

Dataset

In this thesis the dataset 'MPI-Leipzig Mind-Brain-Body' (Babayan et al., 2020; Harvard Dataverse, 2020) was used, which consists of MRI and behavioral data from 318 subjects. All the participants have undergone either the Leipzig Mind-Body-Brain Interactions (LEMON) protocol (Babayan et al., 2019) or the Neuroanatomy & Connectivity Protocol (N&C) (Mendes et al., 2019). Some of the participants participated in both these protocols.

To measure the cognitive ability of divergent thinking, the creative achievement questionnaire (CAQ) has been used. As mentioned before, divergent thinking is highly correlated with creative achievement and thus the CAQ can be used (Ishiguro et al., 2022). The CAQ is a self-report questionnaire which contains 96 items and assess achievement across 10 domains in creativity: visual arts, dance, music, drama, culinary arts, architecture, creative writing, humor, science, and invention (Carson et al., 2013). Each domain consists of 8 rank-ordered questions ranging from 0 to 7 in hierarchical order. A higher score on the report suggests a higher level of creativity.

Image acquisition

All participants were scanned on a whole-body Siemens 3T MRI scanner (Magnetom Verio, Siemens Healthcare, Erlangen, Germany), equipped with a 32-channel Siemens head coil (Babayan et al., 2020).

Several participants assigned to the N&C procedure (109 out of the 119 participants) took part in both protocols. For these overlapping participants the structural data of the LEMON procedure is used. Of unique N&C participants a T1 weighted image and a low-resolution FLAIR image is obtained.

Both protocols used the same MRI parameters. Given that, this thesis used the LEMON T1 weighted imaging data for the participants who took part in both protocols, and the N&C T1 weighted imaging data for the participants who only participated in the N&C protocol (MP2RAGE, 176 slices, voxel size=1.0 mm isotropic, TR=5000 ms, TE=2.92 ms, FOV =256 mm, flip angle 1=4°, flip angle 2=5°) (Mendes et al., 2019).

Furthermore, compared to the 30ms echo time of the rs-fMRI in the LEMON procedure, the N&C procedure used an echo time of 39.4ms. Due to the latter, inconsistency is prevented in this thesis by the usage of solitarily N&C rs-fMRI data.

Four sessions of eyes-open resting-state blood oxygenation level-dependent (BOLD) fMRI scans were performed. Participants were instructed to keep their eyes open and lay still for 15 minutes. The rs-fMRI runs were acquired in axial orientation, using T2*-weighted gradient-echo echo planar imaging (GE-EPI) with multiband acceleration, sensitive to blood oxygen level-dependent (BOLD) contrast (64 slices, voxel size=2.3mm isotropic, imaging matrix=88x88, TR=1400 ms, TE=39.4 ms, flip angle=69°, 657 volumes). Although four rs-fMRI runs are acquired, only the first run was used for each participant due to the limited time of this thesis. The phase-encoding direction for this run was Anterior-Posterior (A–P).

Participants

The sample used for this study was taken from the N&C protocol. Only participants with an CAQ-score were selected (n=75). A between-group approach is utilized to ensure that the independent variable is effective and to prevent carry-over effects. The thresholds for defining the groups are based on percentiles; participants at the bottom 33% were assigned to the LOWER-creative group and participants at the top 33% were assigned to the HIGHER-creative group. The middle group of 33% is excluded from the analysis. This given leaded to a CAQ-score of <1.609 for the lower threshold and >2.485 for the upper threshold. These thresholds were chosen based on a forgoing study of Beaty et al. (2014) to ensure that the group sizes were large enough.

ROI

Several regions of interest (ROIs) have been chosen to examine the differences in functional connectivity of the two participant groups: participants with higher and lower scores achieved on the CAQ. Based on previous studies, the medial prefrontal cortex (mPFC), the posterior cingulate cortex (PCC) and the adjacent precuneus, and bilateral inferior parietal lobes – four major nodes of DMN – are chosen as ROIs. *xyz*= −42, –68, 38 for the inferior parietal lobe left (IPL), *xyz*= (48, –60, 38) for the inferior parietal lobe right (IPL), *xyz*= 0, 54, −8 for the medial prefrontal cortex (mPFC), *xyz*= 0, –56, 28, for the posterior cingulate cortex/ precuneus (PCC) (Beaty et al., 2014). Table 1 shows the ROIs and their brain coordinates and in figure 1 the regions of interest are visualized.

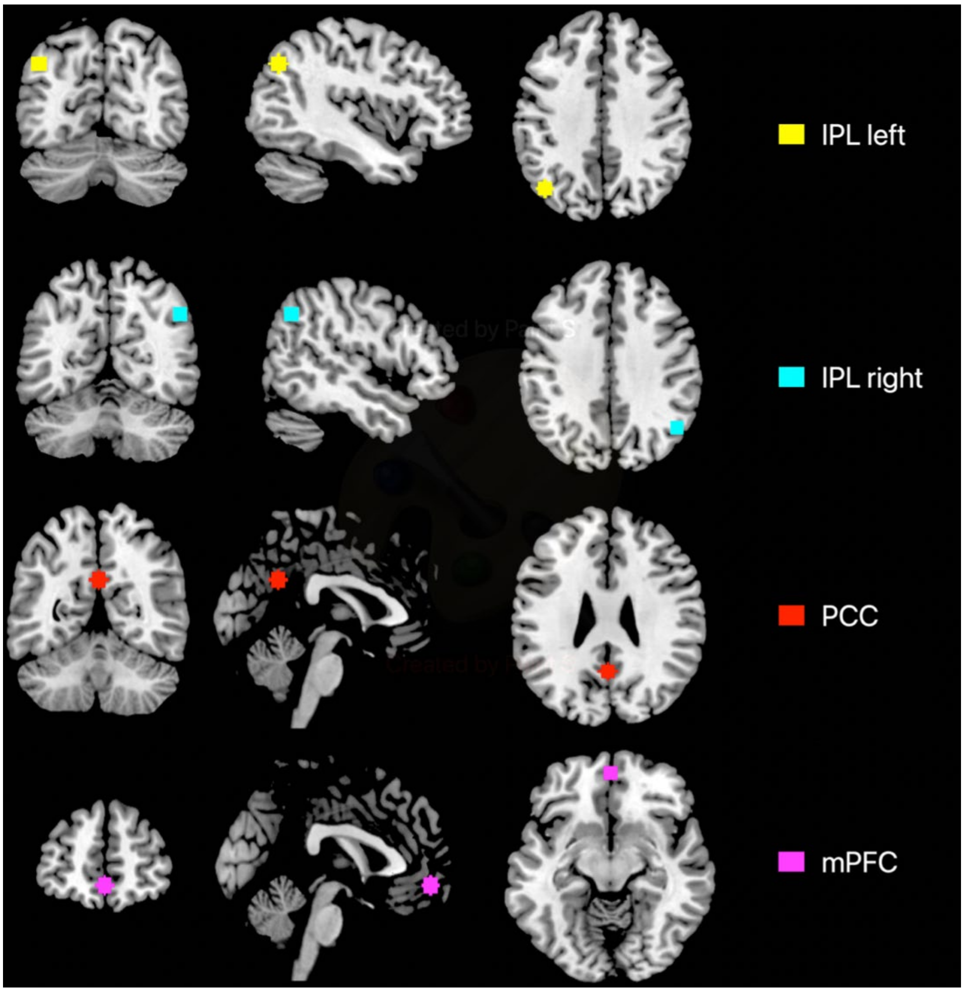
Table 1.

The Regions of Interests (ROIs) and their Brain Coordinates

ROI	x	y	z
IPL left	–42	–68	38
IPL right	48	–60	38
PCC	0	–56	28
mPFC	0	54	–8

Figure 1.

The Regions of Interest in MNI space



Note. Visualized with MRIcron (v1.0.20190902). Overlaid on Ch2.better template.

Data preprocessing

With the usages of the CONN Toolbox (Nieto-Castanon, 2020) and the SPM12 software (SPM, 2020) in Matlab (R2022a), all the rs-fMRI data has been preprocessed. The preprocessing is performed in sequential steps; rs-fMRI images were co-registered and resampled to the first scan, motion corrected, slice time corrected, segmented in gray matter/white matter/CSF, normalized to MNI-space, and smoothed with a Gaussian kernel of 6 mm full-width at half maximum (FWHM). Following this preprocessing, the data was denoised using a temporal band-pass filter (0.008–0.09 Hz) and linear regression to identify and eliminate any potentially pertinent confounding factors. White matter signals, ventricular system signals, estimated realignment and scrubbing parameters, and unwanted linear trends were all considered potential confounds. The three included ROIs—the left and right IPL, PCC and mPFC—were used in this ROI-to-ROI analysis.

The representative time series were obtained for each ROI by averaging the BOLD time series over all of its voxels. The Pearson correlation coefficient between each pair of nodes' time series, which was subsequently Fisher transformed, was calculated for each participant to construct a weighted adjacency matrix that contained the functional connectivity values.

Statistical analysis

For the statistical analysis SPSS (version 29.0.1.0) is used. The sample was tested for meeting the independent t-test assumptions, which include the correct scale of measurement, independence of observation, the absence of significant outliers, normal distribution, and homogeneity of variance. Participants who scored above or under the first and third quartile were considered as outliers and, therefore, excluded. Thereafter, an independent t-test is performed to compare whether the LOWER-group and HIGHER-group differ significantly on terms of their CAQ-scores. The alpha used for this analysis is .05.

The demographic variables "age" (in 5-year bins) and "biological sex" (per group) were computed by descriptive statistics to create a distribution of these two variables. Any age details for participants were not provided in further depth.

Furthermore, the sample was tested for meeting the Pearson correlation assumptions, which cover the level of measurement, related pairs, absence of outliers, and linearity. A Pearson correlation analysis is conducted to measure for any linear correlation between CAQ-scores and the average FC. An alpha level of .05 is used for this test.

With six independent t-test, a statistical analysis was performed to show whether the group ‘HIGHER’ had a significantly stronger FC compared to the ‘LOWER’ group.

Eventually, six independent t-tests were performed to show whether the group ‘HIGHER’ had a significantly stronger FC compared to the ‘LOWER’ group. In order to account for multiple comparisons, p-values were adjusted using the Bonferroni correction. The p-values were determined using the following formula since the actual LOWER-creative group had a greater mean for FC than the HIGHER-creative group did: 1 – p-value one sided. This was contrary to the originally stated one-sided hypothesis.

Results

First, the sample was checked on any violation of the assumptions of all independent t-test assumptions. All assumptions were met, and the sample was robust against violation of the assumption of normal distribution. The first independent t-test confirmed that the LOWER-group and HIGHER-group significantly differed on terms of their CAQ-scores (t (48) = –14.360 ; $p < .001$) which is shown in table 2. The descriptive statistics are as follows: the LOWER-group showed a higher mean on FC (M = 1.121 ; SD = 0.469) than the HIGHER-group (M = 2.964 ; SD = .437) The distribution of gender and age in 5-year bins can be seen in table 3 and 4.

Table 2.

Distribution of participants and mean CAQ score

	N	Mean CAQ score
Lower	25	1.121
Higher	25	2.964

Table 3.

Distribution of gender per group

	Gender	Frequency	Percent
Lower	Male	17	68
	Female	8	32
	Total	25	100
Higher	Male	15	60
	Female	10	40
	Total	25	100

Table 4.

Distribution of age (in 5 bin-years) per group.

	Lower		**Higher**	
Age	N	Percent	N	Percent
20–25	9	36	9	36
25–30	8	32	10	40
30–35	3	12	3	12
35–40	4	16	3	12
40–45	1	4	0	0
Total	25	100	25	100

After the first independent t-test a correlational analysis is conducted to measure if there is any correlation between CAQ-scores and the average FC. Results revealed insignificant correlations in the LOWER-group (r = .209, P = .315) and in the HIGHER-group (r = –.009, P = .996). The results are presented in table 5.

Table 5.

Pearson Correlation analysis of Average FC on CAQ-score.

Group			**Average FC**	**CAQ score**
Lower	Average FC	Pearson correlation	1	.209
		Sig. (2-tailed)		.315
		N	25	25
Higher	Average FC	Pearson correlation	1	–.009
		Sig. (2-tailed)		.966
		N	25	25

With a ROI-to-ROI analysis is the FC between the IFG left, IFG right, PCC and mPFC examined. With six independent t-test, a statistical analysis was performed to show whether the group 'HIGHER' had a significantly stronger FC compared to the 'LOWER' group. In the average FC t-test and in the PCC–mPFC t-test outliers were found. Participants who scored under the first quartile or above the third quartile were excluded. This led to 1 outlier in the LOWER-group in the t-test of PCC– mPFC, and three outliers in the LOWER-group in the t-test of the average FC.

Average FC

The analysis revealed 2 participants who scored above the third quartile and 1 participant under the first quartile, therefore these participants were considered as outliers and, as consequence, excluded from the analysis. There was no significant effect of Average FC on the group variable (t (45) =1.195 ; p = .119). The LOWER-creative group had a greater mean for FC than the HIGHER-creative group so the following formula is used to calculate the p-value corresponding with the hypothesis of this thesis: 1 – p-value one sided. This results in the following findings: insignificant results in average FC(t (45) = 1.195 ; p = .881). These results can be seen in table 6 and figure 2. Due to examining multiple independent t-tests a protection for Type-1 error is needed. Therefore, to determine if any of the t-tests is statistically significantly, the Bonferroni correction is applied, and the p-value must be $p \geq$ .008. This leads to no significant results for the statistical analysis.

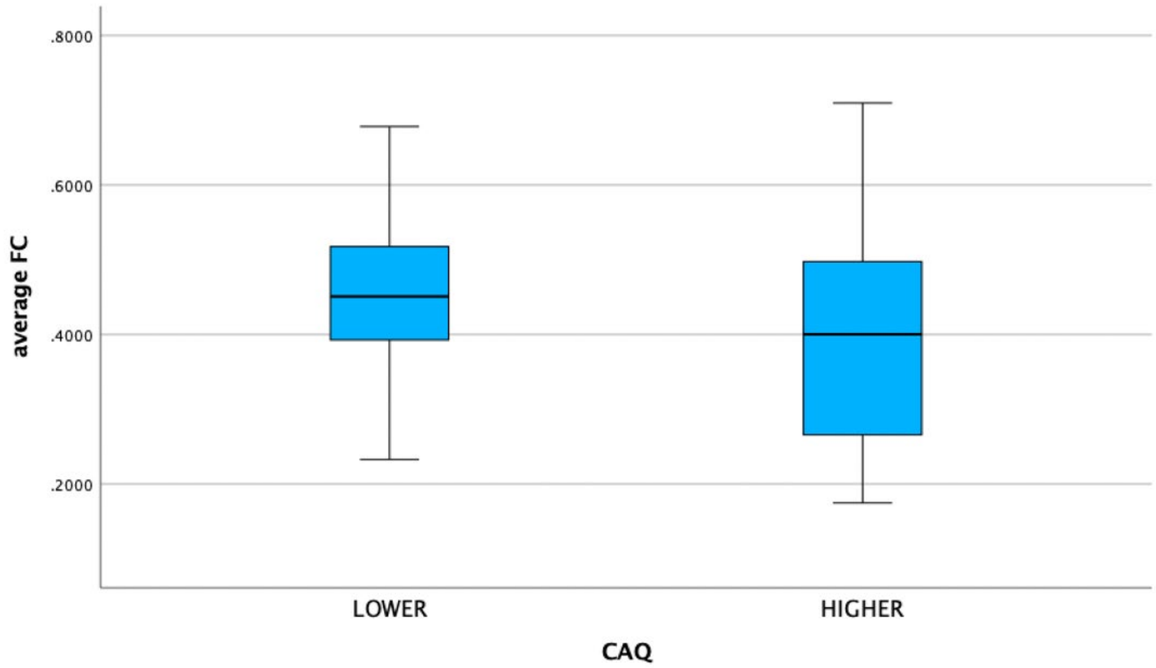
Table 6.

Outcomes of independent t-test for average FC

Average FC	F	Sig.	t	df	One-sided p
Equal variances assumed	.470	.497	1.195	45	.119

Figure 2.

Mean Functional connectivity Average FC



IPL left – IPL right

Results revealed significantly stronger FC in the LOWER-group between the IPL left and IPL right (t (48) = 2.003 ; p = .025), However, since the actual LOWER-creative group had a greater mean for FC than the HIGHER-creative group did, the following formula is used to calculate the p-value corresponding with the hypothesis of this thesis: 1 – p-value one sided. This results in the following findings: insignificant FC between the IPL left and IPL right (t (48) = 2.003 ; p = .975). These results can be seen in table 7 and figure 3. Due to examining multiple independent t-tests a protection for Type-1 error is needed. Therefore, to determine if any of the t-tests is statistically significantly, the Bonferroni correction is applied, and the p-value must be $p \geq .008$. This leads to no significant results for the statistical analysis IPL left – IPL right.

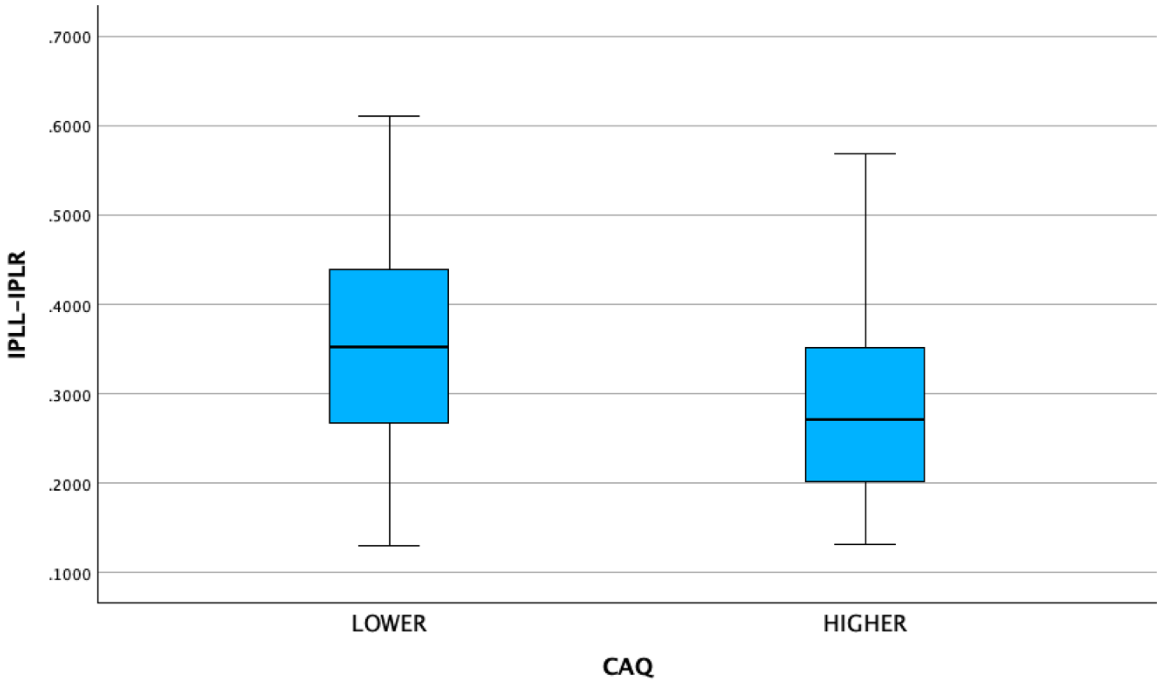
Table 7.

Outcomes of independent t-test for average FC

IPL L–IPL R	F	Sig.	t	df	One-sided p
Equal variances assumed	.145	.705	2.003	48	.025

Figure 3.

Mean Functional Connectivity IPL left – IPL right.



IPL left – PCC

There was no significant effect of the FC scores between the IPL left-PCC on the group variable (t (48) = 1.469 ; p = .074). The LOWER-creative group had a greater mean for FC than the HIGHER-creative group so the following formula is used to calculate the p-value corresponding with the hypothesis of this thesis: 1 – p-value one sided. This results in the following findings: insignificant results for IPL left–PCC (t (48) = 1.469 ; p = .926). These results can be seen in table 8 and figure 4. Due to examining multiple independent t-tests a protection for Type-1 error is needed. Therefore, to determine if any of the t-tests is statistically significantly, the Bonferroni correction is applied, and the p-value must be $p \geq$ .008. This leads to no significant results for the statistical analysis.

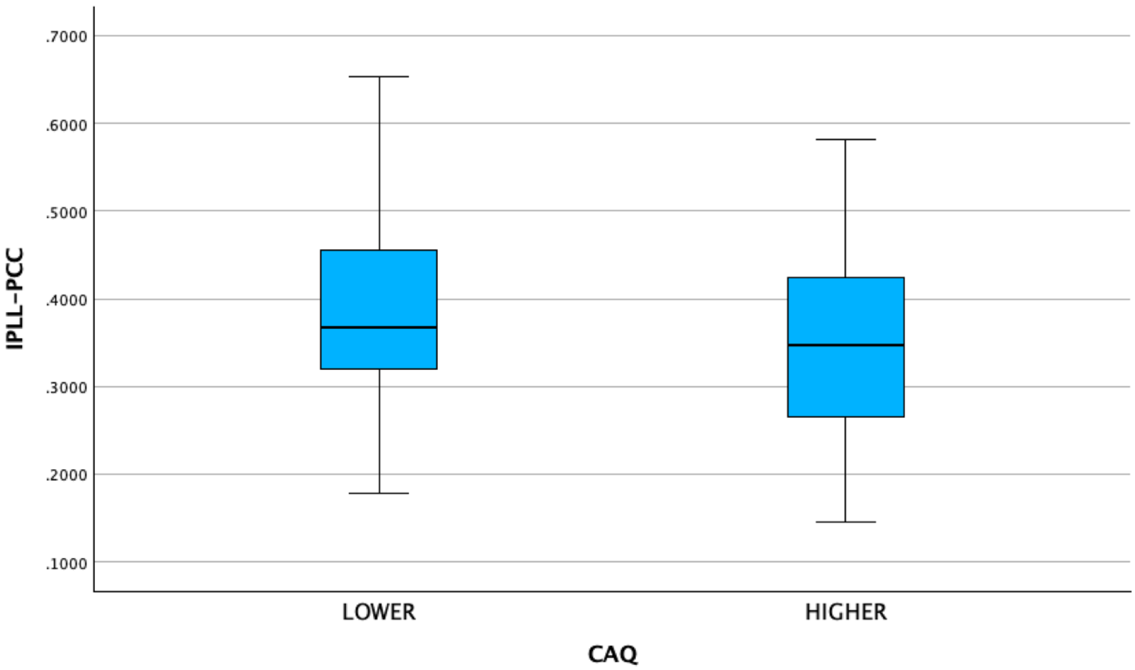
Table 8.

Outcomes of independent t-test for IPL left and PCC

IPL L–PCC	F	Sig.	t	df	One-sided p
Equal variances assumed	.094	.761	1.469	48	.074

Figure 4.

Mean Functional Connectivity IPL left – PCC.



IPL left – mPFC

There was no significant effect of the FC scores between the IPL left and mPFC on the group variable (t (48) = .868 ; p = .195) The LOWER-creative group had a greater mean for FC than the HIGHER-creative group so the following formula is used to calculate the p-value corresponding with the hypothesis of this thesis: 1 – p-value one sided. This results in the following findings: insignificant results for IPL left–mPFC (t (48) = .868 ; p = .805). These results can be seen in table 9 and figure 5. Due to examining multiple independent t-tests a protection for Type-1 error is needed. Therefore, to determine if any of the t-tests is statistically significantly, the Bonferroni correction is applied, and the p-value must be $p \geq$ .008. This leads to no significant results for the statistical analysis.

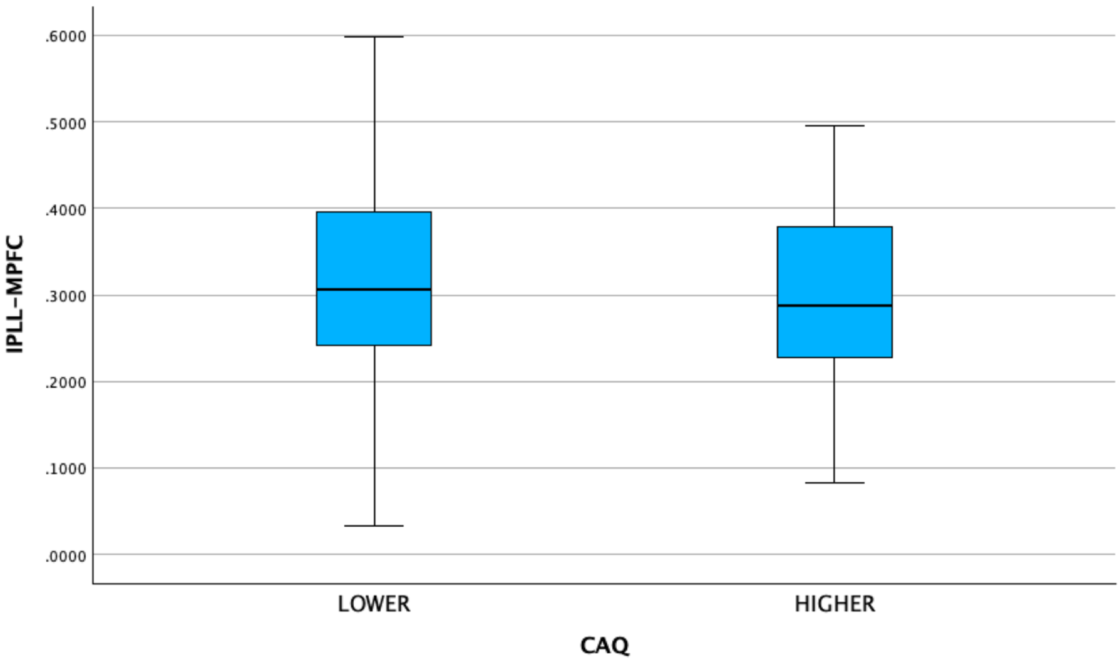
Table 9.

Outcomes of independent t-test for IPL left and mPFC

IPL L–mPFC	F	Sig.	t	df	One-sided p
Equal variances assumed	.170	.682	.868	48	.195

Table 5.

Mean Functional Connectivity IPL left – mPFC.



IPL right – PCC

Results revealed significantly stronger FC in the LOWER-group between the IPL right and PCC (t (48) = 1.897; p = .032). However, since the actual LOWER-creative group had a greater mean for FC than the HIGHER-creative group did, the following formula is used to calculate the p-value corresponding with the hypothesis of this thesis: 1 – p-value one sided. This results in the following findings: insignificant FC between the IPL right and PCC (t (48) = 1.897; p = .968). These results can be seen in table 10 and figure 6. Due to examining multiple independent t-tests a protection for Type-1 error is needed. Therefore, to determine if any of the t-tests is statistically significantly, the Bonferroni correction is applied, and the p-value must be $p \geq .008$. This leads to no significant results for the statistical analysis IPL right – PCC.

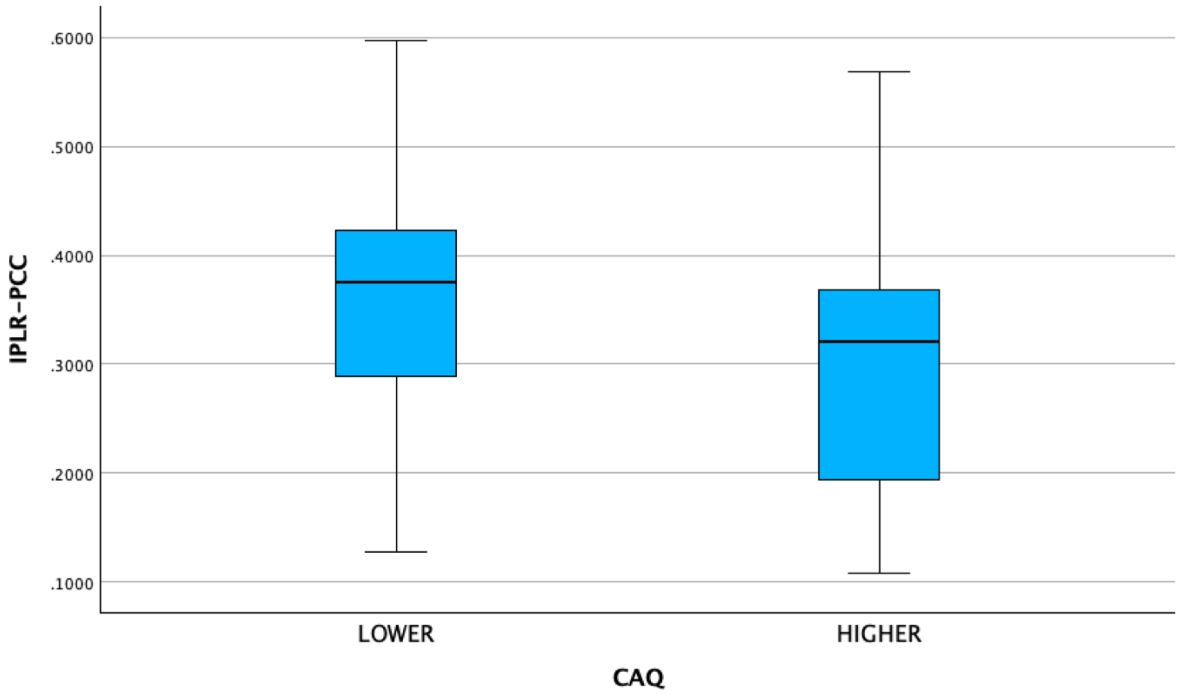
Table 10.

Outcomes of independent t-test for IPL right and PCC

IPL R–PCC	F	Sig.	t	df	One-sided p
Equal variances assumed	.012	.914	1.897	48	.032

Figure 6.

Mean Functional connectivity IPL right – PCC



IPL right – mPFC

There was no significant effect of the FC scores between the IPL right and mPFC on the group variable (t (48) = 1.286 ; p = .102) The LOWER-creative group had a greater mean for FC than the HIGHER-creative group, so the following formula is used to calculate the p-value corresponding with the hypothesis of this thesis: 1 – p-value one sided. This results in the following findings: insignificant results for IPL right–mPFC (t (48) = 1.286 ; p = .898). These results can be seen in table 11 and figure 7. Due to examining multiple independent t-tests a protection for Type-1 error is needed. Therefore, to determine if any of the t-tests is statistically significantly, the Bonferroni correction is applied, and the p-value must be $p \geq$ .008. This leads to no significant results for the statistical analysis.

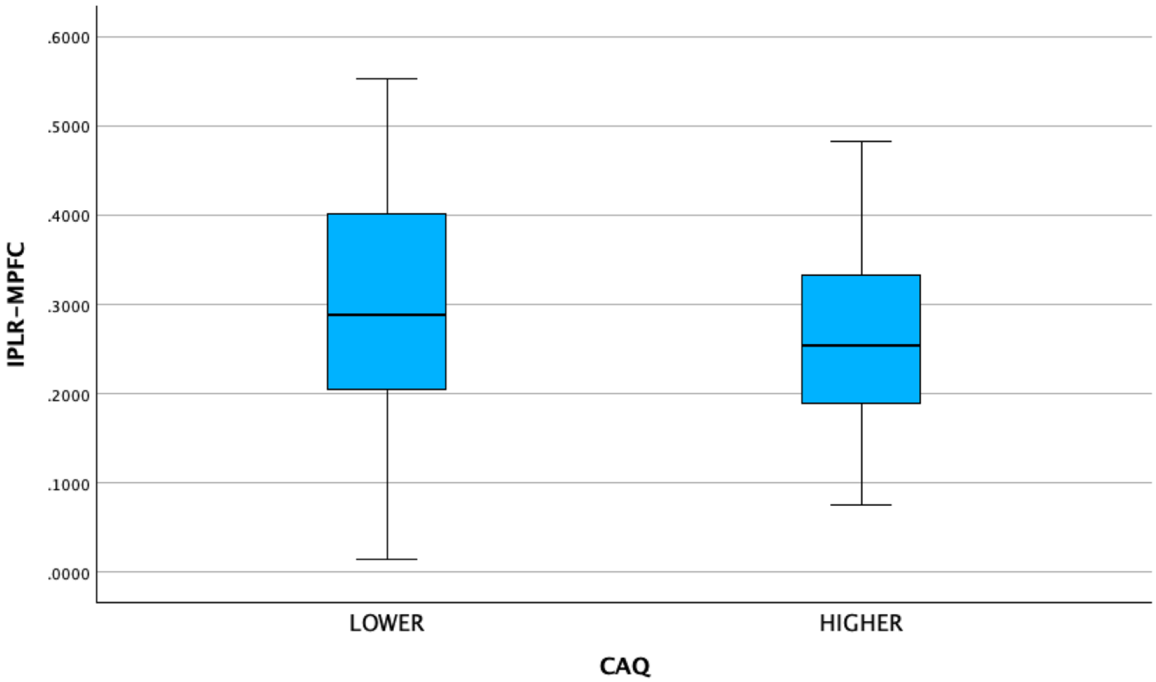
Table 11.

Outcomes of independent t-test for IPL right and mPFC

IPL R–mPFC	F	Sig.	t	df	One-sided p
Equal variances assumed	.876	.354	1.286	48	.102

Figure 7.

Mean Functional connectivity IPL right – mPFC



PCC – mPFC

The analysis revealed 1 participant who scored under the first quartile, therefore this participants was considered as outliers and, as consequence, excluded from the analysis. There was no significant effect of PCC – mPFC on CAQ-scores (*t* (48) = 1.192 ; *p* = .120). The LOWER-creative group had a greater mean for FC than the HIGHER-creative group so the following formula is used to calculate the p-value corresponding with the hypothesis of this thesis: 1 – p-value one sided. This results in the following findings: insignificant results (*t*

(48) = 1.192 ; p = .880). These results can be seen in table 12 and figure 8. Due to examining multiple independent t-tests a protection for Type-1 error is needed. Therefore, to determine if any of the t-tests is statistically significantly, the Bonferroni correction is applied, and the p-value must be $p \geq .008$. This leads to no significant results for the statistical analysis.

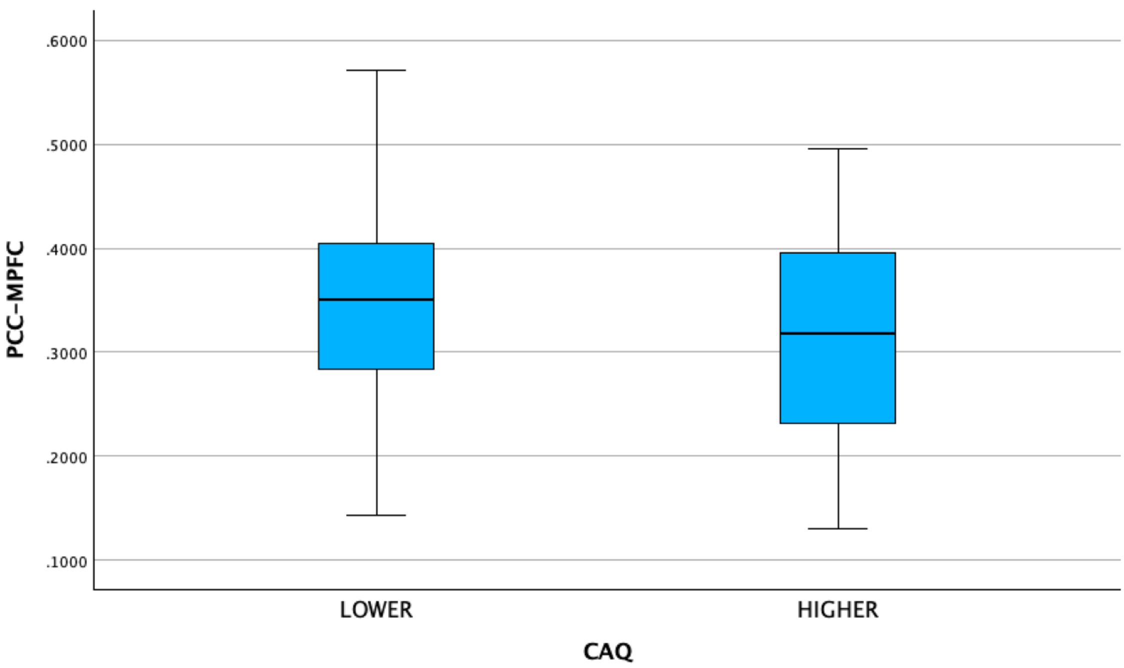
Table 12.

Outcomes of independent t-test for IPL right and mPFC

PCC–mPFC	F	Sig.	t	df	One-sided p
Equal variances assumed	.032	.859	1.192	47	.120

Figure 8.

Mean Functional connectivity PCC– mPFC



Discussion

The present study explored the functional connectivity related to divergent thinking between the IPL left, IPL right, PCC and mPFC. This is examined with the utilization of resting brain state functional imaging to discover the differences between groups with lower- and higher- creative achievement scores. And as mentioned before, these scores are used to measure divergent thinking which predicts the construct creativity (Ishiguro et al., 2022). The intention of this study was to broaden our knowledge about resting brain state FC in healthy highly and lower creative participants. Foregoing studies revealed anatomical differences between these groups by using structural neuroimaging and enlightened the cooperation of DMN and IFG, or ECN, by using functional connectivity neuroimaging. The present study is examined to help us better understand solely the functional connectivity of DMN within higher creative persons. The central question of this study was as follows: is there a difference in functional connectivity in the DMN between people with higher creative achievement scores and people with lower creative achievement scores? Thus, in this thesis is stronger functional connectivity between the certain DMN brain areas – commonly in the literature linked with creativity– within higher creative participants predicted.

Consolidating all findings of this thesis, after the examination of a ROI-to-ROI analysis, there was no significant correlation in either of the groups found between the average functional connectivity and CAQ-score. Moreover, no significant difference in functional connectivity between the lower versus higher divergent thinking groups are found. Therefore, the group who scored higher on divergent thinking do not appear significant stronger functional connectivity between the left IPL, right IPL, PCC and the mPFC. Although no significant results were found, the functional connectivity in the DMN tends to be stronger in lower creatives. By means of this, this thesis did not succeed to conform to the stated hypothesis. Whilst already existing literature found evidence for strong functional connectivity between the PCC and mPFC (Takeuchi et al., 2012), this thesis could not replicate these findings.

This thesis only focused on the functional connectivity within the DMN. And as mentioned before, this consideration is made because of commonly reported supporting results for a relation between the IFG and cognitive control rather than spontaneous cognitive processes, such as the DMN appear to support. Beaty et al. (2014) found evidence for stronger functional connectivity between the IFG and the DMN in people with a higher creative ability. The IFG is frequently associated with the executive control network (ECN) (Hu et al., 2019; Sunavsky & Poppenk, 2020). Continuing that, Chen et al. (2023) found a co-activation pattern between the ECN and DMN. Considering these previous findings of Beaty et al. (2014) and Chen et al. (2023), it could be possible that the cooperation between the DMN and ECN is more important concerning divergent thinking than solely the FC between the DMN nodes. These findings may support the notion that the theory that creative thinking involves both controlled and spontaneous cognitive processes rather than only spontaneous cognitive processes.

The absence of significant findings in this study implies that the higher creative ability does not result in stronger functional connectivity between the IPL left, IPL right, PCC and mPFC. In the study of Takeuchi et al. (2012) results suggested the opposite. There has been a significant increased FC found between the PCC and mPFC in higher creatives compared to lower creatives.

This contradiction can be a consequence of the limitations of the implementation of this research method. The first apparent limitation is the utilisation of a sample size of 75 participants. Due to the time limits of this thesis and limited storage capacity of the computer that is used, a more convincing sample size was not feasible. In addition, the 'MPI-Leipzig Mind-Brain-Body' dataset, which was the only available dataset for this thesis, consisted of a total of 79 participants with both CAQ and resting brain state fMRI data. This means that, after applying 33% thresholds for the division of the groups, the ultimate sample size per group could have been n=26 when using all eligible participants. Conquering this limitation by implementing a larger sample size would result in a higher external validity and increases the statistical power. Secondly, there are some concerns which need to be addressed regarding the statistical analysis that has been chosen for this study. Exclusively the t-tests could be conducted in this thesis despite the preference of an ANCOVA. This limitation is due to a sample size of 25 participants per group, and as mentioned before, if the time limits of this thesis could have been ignored, the ultimate sample size per group would be n=26 maximum. These small sample sizes indicate that the study was not robust against violation of the assumption of normality of residuals, which demands a minimum of 30 participants in each group. Lastly, the diversity of age in both the LOWER- and the HIGHER-group tend to be uniform. The majority of the participants were under the age of 31. This limitation can have an impact on the scores of the CAQ.

Nonetheless, the study had besides the limitations also several strengths. First of all, the CAQ that has been chosen is a self-report assessment but is presumed to reduce response bias by questioning a given achievement instead of evaluating the participants own creativity (Zabelina et al., 2021). Furthermore, the same imaging scanner has been utilized for all subjects, and in addition to that, all imaging data is acquired with the same guidelines. This leads to good quality imaging data and no confounding effects caused by the procedure.

Research on creativity and its neural underpinnings remains needed because of the deficiency in knowledge about how the functional connectivity of the DMN functions within healthy participants with a higher divergent thinking ability. Although this study failed in replicating the aforegoing findings on stronger FC between particular DMN nodes, the already existing literature suggests a cooperation between the ECN and the DMN. Combining the unsignificant results found in this study with previous founded results, suggests that creativity rather works controlled instead of solely spontaneous. A follow-up study that carefully considers the limitations of this study, might help us replicate aforegoing findings and better understand the working of the DMN within higher creative persons, and thus the neural underpinnings of creativity. Future research should further examine functional connectivity of the DMN with a higher sample size, which is at least large enough to conduct an ANCOVA to control for the covariances age and gender. This will lead to a minimalization of confounding effects and a better external validity.

After all, this study was set out to gain a better understanding of the functional connectivity of the DMN in higher creatives compared to lower creatives. Although in this study no significant differences were found between higher and lower creatives, the results suggest that divergent thinking operates controlled rather than spontaneous. However, other results in the literature confirm that creativity also operates spontaneously. Continued efforts are needed to better understand the underlying neural connectivity of creative people.

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