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The relationship between flow proneness in everyday life and variations in the volume of gray matter in the dopaminergic system: A cross-sectional study

Kavous Salehzadeh Niksirat[a,1], Kaechang Park[b,2], Chaklam Silpasuwanchai[c,d,1], Zhenxin Wang[c,1], Xiangshi Ren[a,c,*]

[a] School of Information, Kochi University of Technology, Japan
[b] Traffic Medicine Laboratory, Research Organization for Regional Alliance, Kochi University of Technology, Japan
[c] Center for Human-Engaged Computing, Kochi University of Technology, Japan
[d] Stamford International University, Bangkok, Thailand

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ABSTRACT

Flow Proneness - FP (i.e., dispositional tendency to experience flow) is subjectively different across individuals. An earlier study demonstrated that FP is correlated with the availability of dopamine receptors in the dorsal striatum including the caudate and the putamen. However, it remains unclear whether FP is associated with gray matter volume variations in the brain. The neuro-anatomical basis of FP has been investigated for the first time in the present study. We conducted a cross-sectional study with a high number of healthy employed Japanese adults (n = 680). We measured FP in different domains of everyday life (work, household maintenance, and leisure time) using a Japanese translation of a Swedish flow proneness questionnaire. We investigated gray matter volume using optimized voxel-based morphometry. As hypothesized, we found a significant region in the dorsal striatum. Our results indicate that an increase in gray matter volume in the right caudate is associated with an increase in overall FP in everyday life. However, the resulting correlation was relatively small (0.13). We discuss the potential reasons underlying these findings. Our findings might have further implications for flow research and well-being.

1. Introduction

Flow is a positive state in which a person is fully absorbed in an activity (Csikszentmihalyi & Csikszentmihalyi, 1988). Flow occurs when the challenge of the activity matches the individual's abilities, goals are clear, and feedback is unambiguous. In this optimal state, one experiences high concentration, low self-awareness, high perceived control over the activity, as well as enjoyment. Flow has been studied in diverse circumstances such as playing sports (Jackson, Ford, Kimiecik, & Marsh, 1998), video games (Harmat et al., 2015), musical instruments (de Manzano, Theorell, Harmat, & Ullén, 2010), as well as painting (Stebbins, Getzels, & Csikszentmihalyi, 1978), writing an essays (Perry, 2009), and driving (Russ, Wagner, Liesner, Küçükay, & Vink, 2016).

Although the flow state can be experienced by anyone, there are remarkable individual differences in flow proneness (FP), i.e., *the "dispositional tendency to experience flow"* (Ullén et al., 2012). A seminal study by Csikszentmihalyi proposed that people with autotelic personality ("*autos*": self, "*telos*": goal), who complete tasks for their own sake rather than to achieve external goals, have higher FP in their life activities (Csikszentmihalyi, 1997). Recent behavioral studies have demonstrated that FP is associated with personality traits such as low neuroticism, high conscientiousness, and high extraversion (Ross & Keiser, 2014; Ullén et al., 2012; Ullén, Harmat, Theorell, & Madison, 2016). Further, FP was associated with intrinsic motivation (Jackson et al., 1998), self-esteem, life satisfaction, fulfillment, psychological well-being (Asakawa, 2010), and novelty seeking (Teng, 2011).

A growing body of research has studied physiological (Harmat et al.,

* Corresponding author at: 185 Miyanokuchi, Tosayamada, Kami City, Kochi 782-8502, Japan.
E-mail addresses: kavous.salehzadeh@gmail.com (K. Salehzadeh Niksirat), park.kaechang@kochi-tech.ac.jp (K. Park), chaklam.silpasuwanchai@stamford.edu (C. Silpasuwanchai), chaklam.silpasuwanchai@stamford.edu (Z. Wang), xsren@acm.org (X. Ren).
[1] 185 Miyanokuchi, Tosayamada, Kami City, Kochi 782-8502, Japan.
[2] 2 Chome – 4 – 36, Chiyorichō, Kochi 780-0806, Japan.

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2015; Keller, Bless, Blomann, & Kleinböhl, 2011; Peifer, Schulz, Schächinger, Baumann, & Antoni, 2014) and neural (Harris, Vine, & Wilson, 2017; Klasen, Weber, Kircher, Mathiak, & Mathiak, 2012; Ulrich, Keller, & Grön, 2016; Ulrich, Keller, Hoenig, Waller, & Grön, 2014) substrates of flow. However, these studies focused on investigating the state of flow rather than the underlying reasons for individual differences in experiencing flow. Recently, researchers using a positron emission tomography (PET) investigated the relationship between FP and dopaminergic system (de Manzano et al., 2013). The study demonstrated that individuals with higher FP for daily tasks have higher striatal dopamine D2 receptors. Specifically, the study showed that FP is highly associated with dopamine D2 receptors in the dorsal striatum (caudate and putamen) but not in the ventral striatum. Further, the study showed that FP in different domains of everyday life (i.e., work time, household maintenance, and leisure time) has a similar relationship with dopamine D2 receptors in the dorsal striatum. This was further confirmed by results of Gyurkovics et al. (2016) who found an association between FP and variations in the gene coding dopamine D2 receptors.

Despite these studies, it remains to be established whether the neural differences in brain structure may account for FP in everyday life. Although no study has examined the relationship between striatal gray matter volume (GMV) and FP, there are morphometric studies that have scrutinized gray matter changes in the dorsal striatum. For example, reduced GMV in the dorsal striatum has been observed in individuals with higher sensitivity to rewards (Barrós-Loscertales et al., 2006), while enjoyment has been argued as a reward signal during the flow state (Csikszentmihalyi & Csikszentmihalyi, 1988). In addition, it has been reported that increases in striatal GMV are correlated with creativity (Takeuchi et al., 2010), which is one of the possible consequences of the flow state (MacDonald, Byrne, & Carlton, 2006).

According to the best of our knowledge, this is the first morphometric study analyzing the association between FP and GMV. Building upon the aforementioned study from de Manzano et al. (2013), we hypothesized that GMV changes of the dorsal striatum would correlate positively with an overall FP. To address this issue, we conducted a cross-sectional study with a high number ($n = 680$) of healthy employed Japanese adults. We measured the frequency of different flow factors such as challenge-skill balance (i.e., the challenge of the activity matches ability of the person), goals (i.e., the person has a clear picture of what (s)he wants to achieve), self-awareness (i.e., the person loses the awareness of self during the activity), concentration (i.e., the person feels concentrated during the activity), control (i.e., the person has a sense of control over the activity), and enjoyment (i.e., the person really enjoys the activity) (Klasen et al., 2012) in three domains of everyday life (work, household maintenance, and leisure time). Brain structure was measured using Magnetic Resonance Imaging (MRI) and analyzed with optimized Voxel-based Morphometry (VBM) (Good et al., 2001).

2. Materials and methods

2.1. Participants

A total of 778 healthy subjects (i.e., with no neurological disorders) were examined from April 2016 to December 2016 in the Kochi Kenshin Clinic that is affiliated with Kochi University of Technology, Japan. To keep the flow measurement consistent across three life domains, unemployed subjects were excluded from the study (73 cases). Furthermore, MRI data that could not pass the quality check (19 cases) and incomplete questionnaire data (6 cases) were excluded. Data from 680 Japanese subjects, aged 26–76 (mean = 50.61, SD = 8.78) were analyzed (396 males, mean = 50.55, SD = 9.38, range = 26–76; 284 females, mean = 50.69, SD = 7.88, range = 32–72). All subjects lived in Kochi prefecture and visited Kochi Kenshin Clinic for routine health check-ups.

2.2. Procedure

The content of the study was in accordance with The Code of Ethics of the World Medical Association (Declaration of Helsinki) for experiments involving humans, and it was approved by the local ethical committee of Kochi University of Technology. Subjects were introduced to the content of the research. All subjects signed an informed consent and filled demographic information including health background. Next, subjects were instructed to complete the questionnaire using a tablet and underwent an MRI brain scan.

2.3. Questionnaire

The Japanese version of the Swedish flow proneness questionnaire (Ullén et al., 2012) was used to measure FP in everyday life. The SFPQ has been recently used in several studies (de Manzano et al., 2013; Gyurkovics et al., 2016; Mosing et al., 2012; Mosing et al., 2012). The SFPQ was translated into Japanese by a native Japanese-speaking translator and then revised and verified by two of the authors (see Appendix A). The SFPQ measures three domains of FP in everyday life including work time (FP-Work), household maintenance (FP-House), and leisure time (FP-Leisure). Each domain was assessed by a 7-item questionnaire measuring the frequency of different factors of flow (challenge-skill balance (2 items), goals, self-awareness, concentration, control over activity, and enjoyment). Questions were rated on a 5-point Likert-scale from 1 (never) to 5 (everyday, or almost every day).

2.4. MRI data acquisition

We used a 1.5-T MRI system (ECHELON Vega; Hitachi Medical Corporation, Tokyo, Japan) to collect structural images. A three-dimensional T1-weighted Magnetization Prepared Rapid Gradient Echo (MPRAGE) was obtained (repetition time (TR) = 9.2 ms, echo time (TE) = 4 ms, flip angle (FA) = 8°, field of view (FOV) = 240 mm^2, T1 = 1000 ms, matrix = 256 × 256 × 170, voxel size = 1 × 1 × 1 mm^3, 170 axial slices).

2.5. Behavioral analysis

Behavioral data were analyzed using IBM SPSS Statistics 23. Cronbach's-α was used to check the internal consistency and reliability of the Japanese version of the SFPQ. Overall FP (FP-Total) was calculated by averaging the three life domains. The effects of *life domains* and *gender* were analyzed using mixed Analysis of Variance (ANOVA). Mauchly's test was used to check sphericity, and Bonferroni correction was used for post hoc analyses. The correlations between FP domains were checked using Pearson's product-moment partial correlation test.

2.6. Image analysis

To assess the association between GMV and FP, T1-weighted images were analyzed with FSL-VBM 1.1 (Douaud et al., 2007) (http://fsl.fmrib.ox.ac.uk/fsl/fslwiki/FSLVBM). An optimized VBM protocol (Good et al., 2001) was carried out with FSL tools (FMRIB Software Library, The University of Oxford) (Smith et al., 2004). Data processing was conducted in the following steps: 1) Brain extraction with neck removal option was applied to structural images. 2) Extracted brain images were segmented into gray matter, white matter, and cerebrospinal fluid. 3) Gray matter images were registered to the Montreal Neurological Institute (MNI) 152 standard space using non-linear registration (Andersson, Jenkinson, & Smith, 2007). 4) The resulting images were averaged and flipped along the x-axis to create a left-right symmetric, study-specific gray matter template. 5) All native gray matter images were non-linearly registered to the study-specific template and modulated to correct for local expansion/contraction due to the non-linear component of the spatial transformation. 6) The modulated gray matter images were then smoothed with an isotropic Gaussian kernel with a $\sigma = 3$ mm (full width at half maximum, FWHM = 7 mm). 7) A region of interest (ROI) mask covering the bilateral caudate and the putamen (dorsal striatum) was created using an MNI structural atlas. The resulting mask was thresholded and binarized before being applied to the gray matter mask. 8) A General Linear Model (GLM) was applied using permutation-based non-parametric methods, correcting for multiple comparisons across space (5000 permutations) (Winkler, Ridgway, Webster, Smith, & Nichols, 2014). We tested a single-group average with additional covariates correlating GMV with FP-Total (interest covariate) whilst controlling for age and gender (nuisance covariates). Prior to the statistical test, all covariates (FP, age, and gender) were demeaned (i.e., mean of data was subtracted from all scores). 9) The significance level with the familywise error (FWE) corrected using threshold-free cluster enhancement (TFCE) (Smith & Nichols, 2009) was set at $p < 0.05$ across the ROI. 10) GMV of the significant clusters were extracted, and the nuisance covariates were regressed out from the FP-Total before the correlation test (Beckmann, Jenkinson, & Smith, 2003). 11) To avoid circular analysis (Vul, Harris, Winkielman, & Pashler, 2009), the effects of other variables (FP-Work, FP-House, FP-Leisure) were tested separately using independent contrasts.

3. Results

3.1. Behavioral data

Descriptive statistics are shown in Table 1. The SFPQ showed good internal consistency (Cronbach's-α = 0.85) for FP-Total. A two-way mixed ANOVA was conducted to analyze the effect of *life domain* (within-subject factor) and *gender* (between-subject factor) on FP (dependent variable). Fig. 1 illustrates FP data across different *life domains* and *genders*. Mauchly's Test of Sphericity indicated that the assumption of sphericity had been violated ($\chi^2(2) = 45.70$, $p < 0.001$), and therefore, a Hyunh-Feldt correction was used ($\varepsilon = 0.94$). There was a main effect for *life domain* ($F_{1.8,1278.2} = 579.1$, $p < 0.001$, $\eta^2 = 0.46$) on FP. Post hoc comparison using Bonferroni test indicated that FP-Work was significantly higher than FP-House ($p < 0.001$, Cohen's $d = 1.49$) and FP-Leisure ($p < 0.001$, Cohen's $d = 0.44$). Also, FP-Leisure was significantly higher than FP-House ($p < 0.001$, Cohen's $d = 0.99$). There was a main effect for *gender* ($F_{1,678} = 105.4$, $p < 0.001$, $\eta^2 = 0.13$) on FP showing higher FP for females compared to males. There was also an interaction effect of *life domain* × *gender* ($F_{1.8,1278.2} = 323.1$, $p < 0.001$, $\eta^2 = 0.32$) on FP. Pairwise comparisons showed females had higher FP-House than males ($p < 0.001$, Cohen's $d = 1.99$), while they had lower FP-Leisure compared to males ($p < 0.05$, Cohen's $d = 0.16$). Detailed statistical correlation tests regarding the FP domains, age, and gender are shown in Appendix B.

Table 1
Descriptive statistics and reliabilities of the Japanese version of the SFPQ.

	Cronbach's-α	mean	median	SD
FP-Total	0.85	3.02	2.95	0.57
FP-Work	0.76	3.54	3.50	0.65
FP-House	0.90	2.31	1.57	0.97
FP-Leisure	0.84	3.21	3.14	0.83

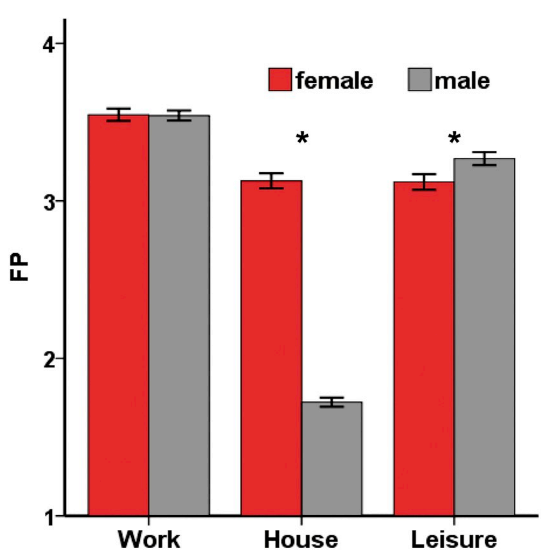

Fig. 1. FP in everyday life across different life domains and genders. Error bars indicate ± SE.

3.2. Neuroimaging data

Fig. 2 shows the results. Optimized VBM ROI analysis detected a cluster of gray matter that showed a positive correlation with FP-Total. The significant cluster (number of voxels = 56, cluster volume = 448 mm^3) was found on the right caudate nucleus (local maximum at x, y, z = 20, 0, 20, center of gravity at x, y, z = 16, 0, 20, $p < 0.05$, FWE–corrected, t-value = 3.91, Cohen's $d_z = 0.15$) (Rosenthal, 1991). After controlling for age and gender (Beckmann et al., 2003), we found a weak correlation between GMV of the significant cluster (the right caudate nucleus) and FP-Total ($r = 0.13$, $p < 0.001$). Table 2 shows separate correlation analyses between GMV of the significant cluster and FP for different genders and life domains (controlled for age). The results indicate that FP-Total was associated with GMV of the significant cluster for females ($r = 0.13$, $p < 0.05$) and males ($r = 0.13$, $p < 0.01$). In addition, we found that FP-House was correlated with GMV for females ($r = 0.13$, $p < 0.05$) and FP-Leisure with GMV for males ($r = 0.12$, $p < 0.05$). We further explored VBM ROI analyses for FP of each particular life domain. However, we could not find a significant cluster (FP-Work: $p = 0.11$; FP-House: $p = 0.22$, FP-Leisure: $p = 0.06$, FWE–corrected).

4. Discussion

To the best of our knowledge, this is the first study investigating the association between individual differences in FP and structural brain alterations. Our findings showed that, as hypothesized, FP-Total is significantly correlated with gray matter changes in the right caudate nucleus. This is congruent with the previous finding that FP is associated with the dopaminergic system in the dorsal striatum (de Manzano et al., 2013). Thus, our results may suggest that individuals who have greater GMV in the right caudate nucleus might more frequently experience the flow state in their daily activities.

4.1. Striatal gray matter

Our findings demonstrated a significant gray matter increase in the right caudate. This is congruent with an earlier study (de Manzano et al., 2013) showing that the association of the FP with the right hemisphere is stronger than with the left hemisphere. The underlying reason for this asymmetry might be higher dopamine availability in the right caudate (Vernaleken et al., 2007). On the other hand, the previous study (de Manzano et al., 2013) showed that FP has a slightly greater association with the availability of the dopamine receptors in the putamen rather than the caudate, whereas our analyses could not find any significant effect in the putamen. However, the relationship between the availability of dopamine receptors and gray matter has not yet been clearly identified. For example, an earlier study (Morales et al., 2015) found that striatal gray matter is positively correlated with the availability of dopamine receptors in methamphetamine users, while this is not true of normal healthy participants. It would be useful to investigate

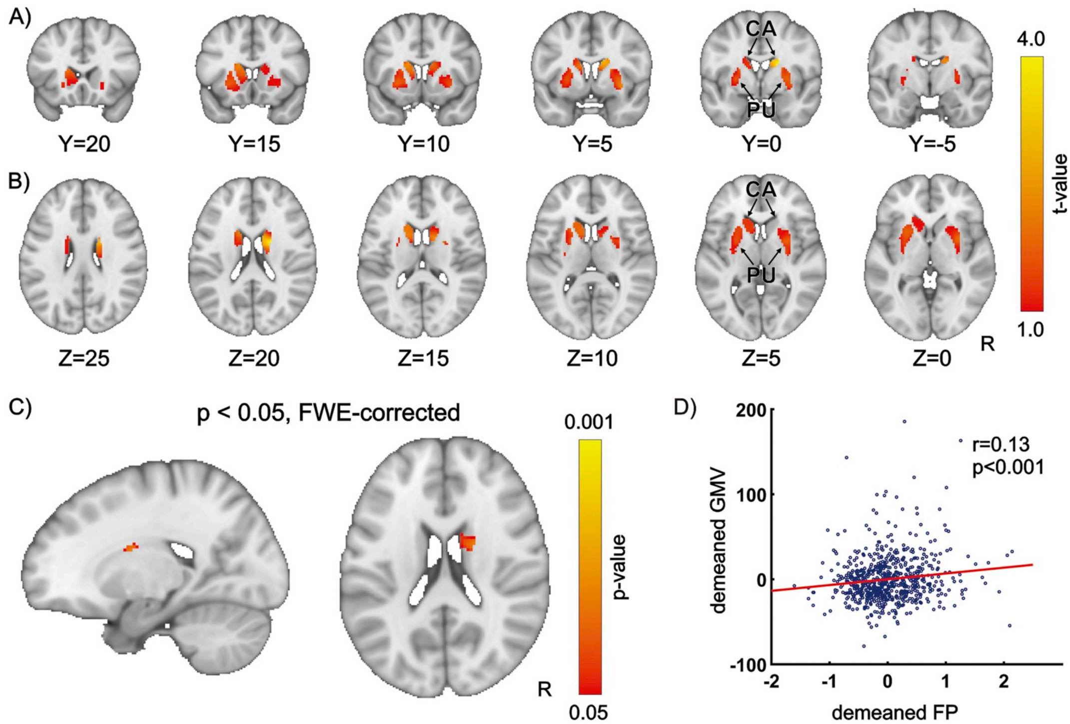

Fig. 2. Correlation of FP-Total and GMV. (A) Coronal view of the t-value with 5 mm slice gaps. The bilateral caudate and putamen are labeled with CA and PU, respectively. The displayed voxels were thresholded between $t = 1$ and $t = 4$. (B) Axial view of the t-value (C) Results of the VBM analysis (local maximum at x = 20, y = 0, z = 20, $p < 0.05$, FWE–corrected, t-value = 3.91). (D) Pearson correlation between GMV of the significant cluster and FP-Total ($n = 680$, r = 0.13, $p < 0.001$).

Table 2
Correlations between GMV of the significant cluster in the right caudate and FP for different genders and life domains.

		FP-Total	FP-Work	FP-House	FP-Leisure
GMV-female	r	0.13	0.06	0.13	0.10
	p-Value	0.03	0.29	0.03	0.10
GMV-male	r	0.13	0.09	0.05	0.12
	p-Value	0.00	0.06	0.32	0.02

this relationship in the future research.

4.2. Flow state

It is worth mentioning that a wealth of research has studied neural substrates of the flow state. Brain activities in reward-related areas, sensorimotor and cognitive networks have been reported while playing a shooting video game in functional MRI (fMRI) (Klasen et al., 2012). In a functional near-infrared spectroscopy (fNIRS) study, Yoshida et al. (2014) found significantly increased activity in the ventrolateral prefrontal cortex during video game play. Employing perfusion fMRI during a mental arithmetic task with automatic adjustment of challenge levels, Ulrich et al. (2014) demonstrated decreased regional cerebral blood flow activity in the medial prefrontal cortex and the amygdala and increased activity in the left anterior inferior frontal gyrus and the left putamen in the flow state. Later Ulrich et al. replicated their study using fMRI (Ulrich et al., 2016) demonstrating consistent findings in a flow condition except in the left putamen. They found additional increased activities in the anterior insula, the basal ganglia and the midbrain. However, all these studies investigated active brain regions in the flow state rather than studying the underlying mechanisms of FP. In addition, functional activation in a brain region does not necessarily indicate a structural change in the same region.

4.3. Attention system

The neurocognitive mechanism of flow experience is closely related to the attention system (Harris et al., 2017), as it is always described as high but effortless concentration (Csikszentmihalyi & Csikszentmihalyi, 1988). Thus, attention deficits might inhibit a person from sustaining the flow state. Several morphometric studies investigated association between attention deficit and striatal gray matter loss. For example, decreased GMV in the caudate nucleus has been observed in Attention Deficit Hyperactivity Disorder (ADHD) (Guillermo, 2010; Seidman, Valera, & Makris, 2005). In addition, attitudes such as impulsivity which are related to attention deficit (Ridderinkhof, Scheres, Oosterlaan, & Sergeant, 2005) might also negatively influence the flow experience. For example, gray matter deficit in the caudate nucleus has been reported in healthy male individuals with lower inhibition (Barrós-Loscertales et al., 2006). Also, similar gray matter patterns have been reported for individuals who have inefficient inhibition against food stimuli (Nouwen et al., 2017). Putting those results together, the relationship between the attention system and gray matter changes in the caudate nucleus may be a plausible underlying mechanism for the present findings.

4.4. Cross-cultural discrepancies

We found a surprising interaction effect with a large effect size for gender and domain, which is not consistent with previous findings (Ullén et al., 2016). Ullén et al. showed that Swedish males experience flow in the house slightly less frequently than females (Cohen's d = 0.24), where as the present study demonstrated that Japanese males have an extremely low tendency towards experiencing flow in house maintenance compared to females (Cohen's d = 1.99). Our findings also clarified that Japanese people experience flow less frequently (FP-Total = 3.02) compared to Swedish individuals (FP-Total = 3.71) (Ullén et al., 2016). In light of the above, we speculate that all these contrasts may be due to the cultural differences between Japanese and Swedish individuals. In the last two decades, a few studies attempted to thoroughly investigate flow experience in Japanese people (Asakawa, 2004, 2010; Csikszentmihalyi & Asakawa, 2016). Although the study of Jujitsu-kan (the Japanese sense of fulfillment) by Asakawa could lead to a better understanding of the flow in the Japanese people generally, gender differences of flow across different life domains have not been studied before. A recent survey of Japanese elementary school students demonstrated that unlike boys, girls have a lower tendency to become breadwinners when they grow up (Daichi-Life Insurance Company, 2018). In addition, regarding remarkable differences in gender parity rankings between Japan and western societies (World Economic Forum, 2017), flow research requires much more cross-cultural investigation in both non-western and western communities.

4.5. Limitations and future work

A potential limitation of the present study is the relatively weak correlation ($r = 0.13$) between FP-total and GMV. However, the significant finding in the dorsal striatum, that has been also supported by earlier studies, indicates that conducting alternative brain analysis may reveal a stronger relationship between the brain and FP. In particular, performing voxel-based functional connectivity analysis of the striatum using a resting-state fMRI may reveal important findings. In addition, investigating white matter structural connectivity of basal ganglia using Diffusion Tensor Imaging (DTI) and Tensor-based Spatial statistics (TBSS) can be useful. Last, regarding the large age range of our dataset and surprising gender differences in our results, conducting statistical analyses considering the effect of age and gender may be a fruitful field of potential future study.

5. Conclusions

This is the first study investigating the relationship of FP in everyday life with structural changes in the dorsal striatum. Increase in overall FP has been associated with gray matter increase in the right caudate nucleus. Our findings imply that greater GMV in the right caudate may result in more frequent occurrence of flow experience. However, the findings have to be interpreted with caution, since we could not precisely derive causal relationships from a cross-sectional study. Behaviorally, we found that employed Japanese adults experience flow more frequently during work time and less frequently during house maintenance. We also found a surprising interaction effect indicating that Japanese males experience much lower flow during household maintenance tasks compared to Japanese females, while they (the males) experience higher flow during leisure time. We suggest further cross-cultural investigations and alternative brain analysis to better understand underlying mechanisms of FP.

Supplementary data to this article can be found online at https://doi.org/10.1016/j.paid.2018.12.013.

Declarations of interest

None.

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