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2 The development of mindfulness in

3 martial arts kendo player: A fMRI

4 analysis of the triple network

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6 (武道剣道選手におけるマインドフルネスの発

7 達：トリプルネットワークの fMRI 解析)

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10 MICHAEL CANTONA SPANTIOS

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18 **The development of mindfulness in martial art kendo players: A**

19 **fMRI analysis of the triple network.**

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21 Michael Spantios MSc BSc¹, Tsukasa Ueno M.D., Ph. D¹, Mami Shibata M.D.¹, Naoya Oishi M.D.,
22 Ph. D¹, Morio Aki M.D.¹, Toshiya Murai M.D., Ph. D¹, Hironobu Fujiwara M.D., Ph. D^{1, 2, 3*}

23

24 ¹Department of Psychiatry, Graduate school of Medicine, Kyoto University, Japan

25 ²Decentralized Big Data Team, RIKEN Center for Advanced Intelligence Project

26 ³The General Research Division, Osaka University Research Center on Ethical, Legal and Social

27 Issues

28 ***Correspondence:**

29 Hironobu Fujiwara.

30 hirofujii@kuhp.kyoto-u.ac.jp

31 This manuscript was written using British English.

32 **Abstract:**

33 Kendo is a martial art that embodies the Zen ideal and practices with bamboo swords, it shares
34 similarities with fencing. Mindfulness is a mental state akin to Zen where one can observe sensations,
35 feelings and thoughts as they happen while remaining impartial to them. Using fMRI of the auditory
36 oddball task we investigated network connectivity based on Menon's triple network theory and

hypothesized that kendo players (KPs) more so than non-kendo players (NKPs) can efficiently switch brain networks from resting to task state, i.e. Default mode network (DMN) to Central executive network (CEN) via Salience network (SN). Preprocessed fMRI and structural MRI data were processed using CONN (ver.18b) with SPM12. A two-tailed t-test was applied for group comparisons of demographic data, average RT to target stimuli in odd, and measures of exercise. We initially performed an ANCOVA with groups (KPs vs. NKPs) as the independent variable, Functional connectivity as dependent variable, and our covariates were age, metabolic equivalent of task (METs) and Oddball reaction times (OddballRTs). Differences were deemed significant if FDR p-values= ≤ 0.05 . KPs had significantly shorter OddballRTs compared to NKPs, with no difference in error rate. Quicker processing but equal task performance suggests better performances in KPs. Overall, moderate positive correlation between all areas of the triple network were found and the ANCOVAs showed a significant difference between the two groups for task FCs, particularly in the SN-CEN and CEN-DMN. During ROI-ROI rs-fMRI, CONN revealed that KPs exhibited significantly lower FC between chosen DMN and CEN ROIs. During task, only higher FCs between chosen DMN-SN plus SN-CEN were found in KPs, and lower CEN-DMN FCs were also present. Higher DMN-SN/SN-CEN network connectivity indicates sharpened network activity in KPs presumably because of habitual training. SN activity would indicate better focus in KPs, showing consistency with our previous analyses. In the future, mindfulness production via sport may be clinically applicable to a range of health promoting programs.

Key words: Triple network, fMRI, Mindfulness, Kendo, Mental health.

Introduction

Within the current literature there is no universally recognised definition of mindfulness as it is still a relatively new field and lack of empirical research has led to no verifiable consensus being reached thus far. However, the working definition of mindfulness suggests that it is a mental state where one can observe sensations, feelings and thoughts as they happen while remaining impartial to them [1]. In a similar vein, John Kabat-Zinn one of the pioneers of the mindfulness-based stress reduction therapy (MBSR) states that it is “awareness that arises from paying attention in a particular way, on purpose in the present moment, and nonjudgmentally to the unfolding of the experience” [2]. Mindfulness was also likened to an “unmoved mind” as described by Zen Master Takuan Soho (1573-

1645) and is a mindset that is able to deal with things in a flexible and unconstrained way, which is different from stagnation [3]. Using a mindfulness strategy called mindful attention has been shown to produce less neural activity in the subgenual ACC, ventral ACC, ventral mPFC and medial orbitofrontal cortex during exposure to stressful scenarios [4]. This achievement of an unperturbed mind can therefore be important in terms of stress coping and the ability to respond to negative events calmly. This has the possibility to lead to novel clinical treatments or even prevention of mental health problems, such as depression and anxiety, that are becoming increasingly common in our daily lives [5].

In relation to the achievement of an unmoved mind, which can be interpreted as cognitive and behavioural instantaneous flexibility [6]. The study by Fujiwara et al. reported an increase functional connectivity (FC) in the motivation network (MN), which is closely related to the reward system, from resting state to attention-related task phase in habitual highly skilled martial art kendo practitioners, suggesting that the resting versus attentionally driven contrast of the FC in MN is consistent with this concept [7]. While the physiological benefits that martial arts provide for you are widely known including the positive impact on the respiratory, metabolic and cardiovascular systems, multiple studies have also shown that mental wellbeing can improve in tangent [8]. Frequent exercise alongside the release of endorphins it provides has been shown to alleviate stress and symptoms of anxiety and depression [9]. FDG-PET (fluorodeoxyglucose Positron Emission Tomography) studies have supported these findings indicating that exercise can determine changes in metabolic networks that are related to cognition through measuring glucose levels and synaptic function [10,11]. These benefits may even include connectivity networks, with aerobic fitness being able to explain individual differences in functional connectivity within the central executive network (CEN), the default mode network (DMN), and attention networks [12]. However, do basic perception and cognitions (e.g., processing and interpretation of external stimuli) influence performance and form the basis of such

92 motivation? To date, neural correlates of basic sensory, perceptual and cognitive functions are still not
93 well understood in habitual exercise practitioners. Thus, this study attempts to help us investigate the
94 mechanisms of possible mental health promotions/ cognitive improvements via the establishment of
95 mindfulness and this mind-body unity that occurs in habitual exercise practitioners.

96 Traditionally, mind-body unity was referred to as "shin-shin ichinyo" in Japanese which stems from
97 the influence and teachings of Zen Buddhism [13]. This form of Buddhism believes that wisdom
98 alongside compassion is essential and should be present in all aspects of everyday life [14]. Kendo is
99 one type of martial art that practices with bamboo swords and shares similarities with fencing. A
100 central tenet of kendo is its ability to integrate both body and mind through intense training
101 methods that are said to increase mindfulness and show "zen in action"[14]. We believe that there are
102 two forms of mindfulness, one which focuses on the internal world of the individual and another which
103 shifts the focus to the external world. The former is helpful in regards to self-reflection and self-
104 actualisation whereas the latter is helpful in maintaining focus/attention on a task. This is a concept
105 that can serve as a further extension of the distinction between interoceptive and exteroceptive
106 attention and a good example of these in action would be meditation as an introspective practice and
107 habitual training in martial arts as an extrospective practice. The type of mindfulness we are
108 investigating in this study is extrospective in nature and we believe it can be effectively achieved
109 through habitual kendo training.

110 The theory we are working off is the triple network theory [15] which suggests that the switching of
111 the default mode network (DMN) to the Central executive network (CEN) is mediated by Salience
112 network (SN) function. The DMN is a network said to be made up of the posterior cingulate cortex
113 (PCC), precuneus (Pre), medial prefrontal cortex (MPFC), inferior parietal cortex (IPC) and the
114 anterior cingulate cortex (ACC). It has a role in self-referential processing, rumination and imagining
115 the future and language. During cognitive task performances the DMN is said to be deactivated [16].

The Salience network is said to be made up predominately of the Insula and ACC. It is involved in the detection of novel stimuli across multiple modalities. The Central Executive Network main nodes are the Dorsal Lateral Prefrontal Cortex (DLPFC) and the Lateral Posterior Parietal Cortex (LPPC). The DLPC is involved with working memory as well as decision making and problem solving with regards to goal-oriented behaviour [15]. The LPPC is involved in integrating sensory and interoceptive information that allows for us to sustain attention. Furthermore, the CEN is also said to be involved with top-down processing necessary for effective emotional regulation [15]. The link between large scale networks and mindfulness is tentative but a recent fMRI study by Bremer et al. indicated an increase in FC between the DMN-SN as well as the SN-CEN in individuals who underwent a 31-day mindfulness meditation training course compared to control [17].

In the present study, we investigated the brain network connectivity of kendo practitioners based on the triple network theory [15]. The triple network was chosen because triple network models have been used to identify a variety of perceptual processing states as well as various psychiatric disorders such as mood disorders, neurodevelopmental disorders and schizophrenia. By using the triple network, we can help to elucidate the mechanisms that lead to better attention regulation and other possible mindfulness traits that can be induced by continuous kendo training. This is why we hypothesized that KPs are both quicker and more easily able to switch their brain networks from resting state to task phase (from DMN to CEN) compared to Non-Kendo Practitioners (NKPs).

Methods

2.1 Participants

Participants were age-matched men KPs (n = 18) and NKPs (n = 20). Inclusion criteria for KPs were defined as individuals of over fourth dan-grade Kendo players (i.e., proficient individuals with a career for over 10 years equivalent to that of an instructor) with habitual practices (twice a week minimum).

There were no exclusion criteria. Two well-trained psychiatrists confirmed that they had neither psychiatric disorder nor severe medical or neurological illness. After the experimental procedures had been fully explained, all participants provided written informed consent before study participation. The study was approved by the Ethics Committee of the Kyoto University Graduate School and Faculty of Medicine and was conducted in accordance with the Declaration of Helsinki. Ethics number: R089.

2.2 The Assessment of General Physical Activity and Other Life Habits

The International Physical Activity Questionnaire (IPAQ; the 7-item short version [18], is a self-rating questionnaire used to measure the average amount of general physical activity over a week. Its indices are the average exercise intensity = multiplication of METs and duration of exercise [metabolic equivalents of task (METs) minutes/day], and the average energy consumption (kcal/day) (<https://sites.google.com/view/ipaq/score>). The revised 2005 version was used and the reliability and validity of the short form of Japanese IPAQ have been confirmed previously [19].

2.3 MRI Acquisition and preprocessing

The procedures of MRI image acquisition and preprocessing were explained precisely elsewhere [7]. Structural MRI data were acquired using 3-dimensional magnetization-prepared rapid gradient-echo (3D-MPRAGE) sequences on a 3-Tesla MRI unit (Tim-Trio; Siemens, Erlangen, Germany). The parameters for the 3D-MPRAGE images were as follows: echo time (TE), 3.4 ms; repetition time (TR), 2000 ms; inversion time, 990 ms; field of view (FOV), 225×240 mm; matrix size, 240×256 ; resolution, $0.9375 \times 0.9375 \times 1.0$ mm³; and 208 total axial sections without intersection gaps. The fMRI acquisition started with a 360-s resting-state scan (Rest) using a single-shot gradient-echo echo planar imaging (EPI) pulse sequence with a 40-mT/m gradient and a receiver-only 32-channel phased-

array head coil. Instructions on the auditory oddball task were given to the participants for 25s after Rest, followed by the task-based scan (390s, 30 randomized target trials and 150 non-target trials making a ratio of 1:5 deviant to standard). All stimuli were presented using E-prime 2.0 software (Psychlab, USA) for 200 ms with a randomized inter stimulus interval (ISI) of 1–3 s in 100 ms units. During the task, participants were instructed to differentiate between target and non-target tones by pressing a button as fast and as accurately as possible after target stimulus presentation. Parameters for the fMRI were as follows: TE, 30 ms; TR, 2500 ms; flip angle, 80; FOV, 212 × 212 mm; matrix size, 64 × 64; in-plane spatial resolution, 3.3125 × 3.3125 mm²; 40 total axial slices; and slice thickness, 3.2 mm with 0.8-mm gaps in ascending order. A dual-echo gradient-echo dataset for B0-field mapping was also acquired for distortion correction. As for Image preprocessing, we did not discard the initial volumes. Instead, potential equilibration effects were accounted for by motion correction, ART-based scrubbing, and denoising (FIX, CompCor). We also visually checked the time series and did not observe systematic artifacts in the early scans [20, 22]. The fMRI dataset was corrected for EPI distortion using FMRIB’s Utility for Geometrically Unwarping EPIs (FUGUE), which is part of the FSL software package (FMRIB’s software library ver.5.0.9) and which unwarps the EPI images based on field map data. Artifact components and motion-related fluctuations were then removed from the images using FMRIB’s ICA-based X-noiseifier (FIX) [20]. The pre-processed fMRI and structural MRI data were then processed using the CONN-fMRI FC toolbox (ver.18b) with the statistical parametric mapping software package SPM12 (Wellcome Trust Centre for Neuroimaging). First, all functional images were realigned and unwarped, slice-timing corrected, co-registered with structural data, spatially normalized into the standard MNI space (Montreal Neurological Institute, Canada), and outliers were detected with ART-based scrubbing (Global signal z-value threshold = 5, Motion threshold = 0.9 mm and Composite motion enabled.) These are the default ART thresholds provided in the CONN toolbox. Images were then smoothed using a Gaussian

kernel with a full-width-at-half maximum (FWHM) of 8 mm.

All preprocessing steps were conducted using a default preprocessing pipeline for volume-based analysis (to MNI space). Structural data were segmented into grey matter, white matter (WM), and cerebrospinal fluid (CSF), and normalized in the same default preprocessing pipeline. Principal components of signals from WM and CSF, as well as translational and rotational movement parameters (with another six parameters representing their first-order temporal derivatives), were removed using covariate regression analysis by CONN. Using the implemented CompCor strategy [21], the effect of nuisance covariates, including fluctuations in fMRI signals from WM, CSF, and their derivatives, as well as realignment parameter noise, were reduced. As recommended, band-pass filtering was performed with a frequency window of 0.008–0.09 Hz. This preprocessing step was found to increase retest reliability. Before running FIX, movement during fMRI was evaluated using framewise displacement, which quantifies head motion between each volume of functional data [22]. Participants were excluded if the number of volumes in which head position was 0.5 mm different from adjacent volumes or was more than 20%. In actuality, no participants were excluded according to this criterion. The distribution of excluded volumes per participant were 0.821 with a SD of 1.819 and there were no significant between group differences (0.632, 1342 vs 1.000, 2,200). Furthermore, there was no significant difference in frame-wise displacement between the KPs and NKPs (0.154, 0.062 vs. 0.145, 0.050, $p = 0.720$).

2.4 Functional Connectivity Analysis

The inter and intra-network analyses of the triple network

We conducted a region of interest (ROI)-to-ROI FC analysis to investigate the inter-network connectivity among the DMN, SN and CEN, as well as the intra-network connectivity, respectively.

We adopted ROIs defined from the Stanford FIND atlas ICA and our inclusion criteria was to select

ROIs previously associated with the triple network using prior studies as evidence [15,17]. There were no specific exclusion criteria but we chose not to include all 50 triple network ROIs specified in the atlas in order to reduce comparisons. We specified 20 spherical clusters with 10-mm diameters that showed peak activation coordinates of each selected region within each of the networks as defined by this atlas ICA. 6 in the DMN (medial prefrontal cortex/anterior cingulate cortex/orbitofrontal cortex, middle frontal gyrus, middle occipital gyrus/angular gyrus, para hippocampal cortex, posterior cingulate cortex/precuneus) which were chosen as they are all core DMN nodes and involved in DMN processes [22,23]. 8 in the SN (middle frontal gyrus, Insular, medial prefrontal cortex/anterior cingulate cortex/supplementary motor area, supramarginal gyrus/inferior parietal gyrus) which are well established ROIs used to represent the SN [24,25] and 6 in the CEN (superior parietal gyrus/inferior parietal gyrus/Precuneus/Angular gyrus, cerebellar Crus1, Thalamus, middle frontal gyrus/superior frontal gyrus and Caudate nucleus) 5 of which are well established nodes of the CEN as they make up the DLPFC and the LPPC [25,26] and the caudate nucleus which has a strong functional connection to the DLPFC as it is involved in cognitive processes like executive function and goal-directed behaviour [27,28]. These ROIs were then matched with the MNI atlas provided by CONN (<https://www.nitrc.org/projects/conn/>) The chosen sphere diameter was based off previous work by Fujiwara et al. 2019 [7]. For detailed ROI coordinates and lateralization, please see supplementary table 7. The lateralisation followed the coordinates as defined in the Stanford find atlas. We did not apply additional lateralisation criteria beyond those defaults.

For each subject, the pre-processed fMRI time series of all voxels in the ROIs were extracted and averaged. ROI-to-ROI FC was defined as the Fisher-transformed bivariate correlation coefficients for each pair of the 20 regions, which resulted in a 20 x 20 correlation matrix (190 FCs) for each participant. Due to the exploratory nature of this study, corrections for multiple comparisons

were performed using the False Discovery Rate (FDR), but not using cluster wise Bonferroni correction, based on the number of ROIs within the networks. The relationship of FC values between two ROIs were compared between the KPs and NKPs using CONN. Establishing a connection, given our chosen ROIs, was prioritised here and we considered it more appropriate to prioritise statistical power rather than type 1 error, but in future follow-up studies, stricter corrections can be applied to further confirm any claims made in this study.

2.5 Connectivity analysis

Intranetwork

After this to further establish the strength of the connections within these networks for the chosen ROIs, a connectivity analysis was conducted in order to find out the average FCs of each network (DMN, SN, CEN). The mean strength (Z) for the intranetwork FCs was defined as $Z_X = \frac{1}{n_x(n_x-1)/2} \sum_{i,j=1:n_x} |z_{i,j}|$ where n_x is the number of ROIs in chosen network X and $\sum_{i,j}$ is the Z score between the i and j ROIs of the chosen network and $\sum_{i,j=1:n_x} |z_{i,j}|$ represent the integrity of the node, similar to degree centrality in graph theory [29].

Internetwork

The strength of the internetwork connectivity was defined as the mean strength of all possible connections present amongst the three networks. The mean strength for the internetwork FCs was defined as $Z_{X,Y} = \frac{1}{n_x n_y} \sum_{i \in X, j \in Y} |z_{i,j}|$ where both X and Y represent the selected networks, n_x and n_y represent the number of ROIs in those networks and $\sum_{i \in X, j \in Y} |z_{i,j}|$ represents the integrity of the nodes between those networks [30]. When calculating mean internetwork FCs and detecting differences in internetwork FCs for kendo vs non-kendo specifically, the CONN toolbox was used.

2.6 Statistical Analysis

Two-tailed t-test was applied for group comparisons of demographic data, average reaction time to the target stimuli in the oddball paradigm, and measures of physical exercise. Subject-specific connectivity matrices for each ROI estimated from the CONN toolbox were used as a second-level analysis. We performed a one-way analysis of covariance (ANCOVA) with group (KP vs. NKP) as an independent variable, FC as a dependent variable and for covariates of no interest we used age, body mass index (BMI), Oddball reaction time average (OddballRTave), and METs which is a measure of exercise intensity. Differences between KP and NKP were deemed statistically significant if false discovery rate (FDR) p-values were less than 0.05.

Results

3.1 Demographic Information, General Physical Activity, and Behavioural Data

Because of the presence of organic brain abnormalities (ischemia, arachnoid cysts), inability to provide written consent or contraindications to MRI (medical metal implants, cardiac pacemakers/prosthetic valves, possible pregnancy, history of metal polishing work, claustrophobia, permanent tattoos/makeup) no subjects were excluded from the KP and NKP group, respectively, resulting in a final total of 18 KPs and 20 NKPs in each group. Demographics and behavioural data of the auditory oddball task are in Table 1. KPs were shorter in the reaction time of the Oddball task (RTs) compared to NKPs, without a difference in the error rate. An Inverse efficiency score (reaction time average/proportion of correct responses) for both KPs and NKPs was calculated to better show this. KPs had an IES of 370.799ms and NKPs had an IES of 429.657ms. We then carried out an independent samples t-test to see if there was a significant difference between the scores. We found that KPs had significantly lower IES scores than NKPs ($t = -2.347$, $df = 37$, $p \text{ value} = 0.024$).

	KP		NKP		
	(N=18)		(N=20)		
	mean	Standard dev	mean	Standard dev.	P value
Age (years)	41.166	11.976	35.952	12.371	0.191
Oddball Reaction					
time_ average (ms)	354.319	78.368	410.561	70.365	0.023*
Body Mass Index					
(BMI) (kg/m ²)	24.417	2.665	23.013	3.185	0.148 ^a
METs (mins/week)	520.349	505.932	314.027	319.055	0.130

Table 1 Demographics and behavioural data during the oddball task

*p < 0.05, a: Welch's t test

3.2 Average Triple network FC for all subjects

To further solidify the relationship between these networks we looked at and calculated the average FCs between all connections of the triple network for all subjects rather than just the significantly correlated areas. We obtained fisher-transformed Z-values of the triple network FCs then converted these values to Pearson's correlation coefficients to see the average strength of the correlations between these networks. We found that there were significant positive correlations between the DMN-SN ($r=0.367$, $p\text{-value} = 0.021$), SN-CEN ($r=0.325$, $p\text{-value} = 0.043$) and verging on significance for the CEN-DMN ($r=0.314$, $p\text{-value} = 0.051$).

3.3 Group differences in Triple Network FCs.

After establishing this, we wanted to see whether there was a significant difference between overall

networks in KPs and non-KPs during the oddball task and at rest. We compared the average fisher transformed Z-values of the networks and differences were deemed significant if FDR p-values were less than 0.05. We initially ran the analysis without controlling for covariates and there were no differences during rest as the DMN-SN had a p-value of 0.798, SN-CEN had a p-value of 0.952 and CEN-DMN had a p-value of 0.158 (see table 1). During task, KPs had lower CEN-DMN connectivity ($p = 0.035$) and higher SN-CEN connectivity ($p = 0.031$) (see tables 2 and 3). Since OddballRTave was seen to be significantly different between the groups we decided to carry out the analysis again but this time controlling only for OddballRTave. At rest there were no differences between the groups but CEN-DMN was approaching significance with a p-value of 0.052 (see table 4). During task the results showed that KPs still had lower FCs in the CEN-DMN ($p = 0.035$) and higher FCs between the SN-CEN ($p = 0.013$) (see table 5).

Networks	Degrees of freedom	F-test value	P-value
Default mode network- Salience network	1	0.068	0.798
Salience network – Central executive network	1	0.004	0.952
Central executive network – Default mode network	1	2.074	0.158

Table 2 ANOVA KP > NKP for triple network connectivity during rest

Networks	Degrees of freedom	F-test value	P-value
Default mode network- Salience network	1	0.372	0.274
Salience network –	1	3.725	0.031*

Central executive network

Central executive network 1 3.460 0.035*
 – Default mode network

309 Table 3 ANOVA KP > NKP for triple network connectivity during task

310 *p < 0.05

Networks	Degrees of freedom	F-test value	P-value
Default mode network- Saliency network	Degrees of freedom	F-test value	P-value
Default mode network – Saliency network – Central Saliency network executive network	1	0.078 0.152	0.391 0.696
Saliency network – Central Central executive network executive network – Default mode network	1	5.336 4.04	0.013* 0.052
Central executive network – Default mode network	1	3.497	0.035*

311 Table 4 ANCOVA KP > NKP when controlling for Oddball Reaction Time average during rest

312 Table 5 ANCOVA KP > NKP when controlling for Oddball Reaction Time average during task

313 *p < 0.05

314

315 3.4 All subjects triple network ROI-ROI FCs

316 Triple network FCs for all subjects both at rest and during task performance are shown in figure 1a

317 and figure 1b. Red indicates that there is a positive correlation between these ROIs, blue indicates

318 that there is a negative correlation.

319

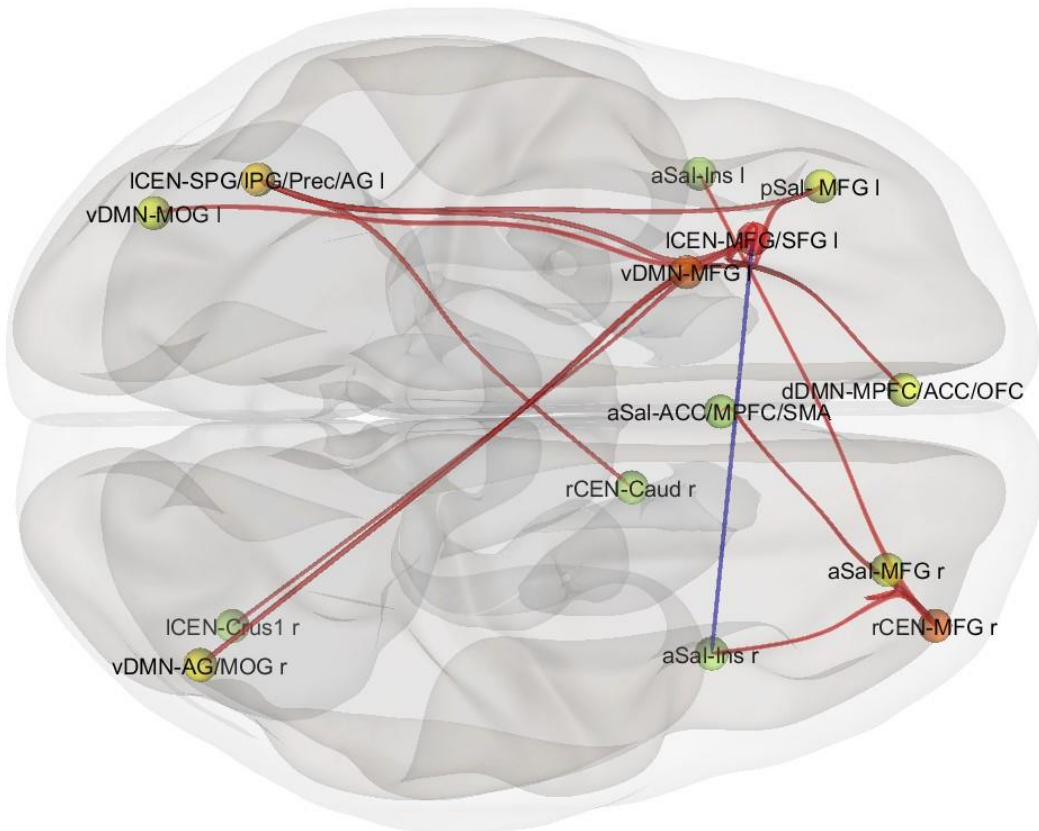
320 During rs-fMRI, the CONN-toolbox analysis revealed that at rest there was decreased connectivity

321 between the anterior SN (Ins r) and the left CEN (MFG/SFG l) but increased activity within various

322 areas of the triple network (**Figure 1a**). During task performance there was increased activity

323 between various regions of the triple network as expected but also decreased activity between the

324 anterior SN (Ins r) and both the ventral DMN (PCC/Prec) and the dorsal DMN (AG/MOG r) (**Figure**
325 **1b**). There was also decreased activity between the ventral DMN (MFG l) and the right CEN (Caud
326 r) (**Figure 1b**).



327
328 **Figure 1a** Triple network FCs for all subjects at rest, significantly correlated ROIs, controlling for age,
329 OddballRTave, METs, $p < 0.05$.

330

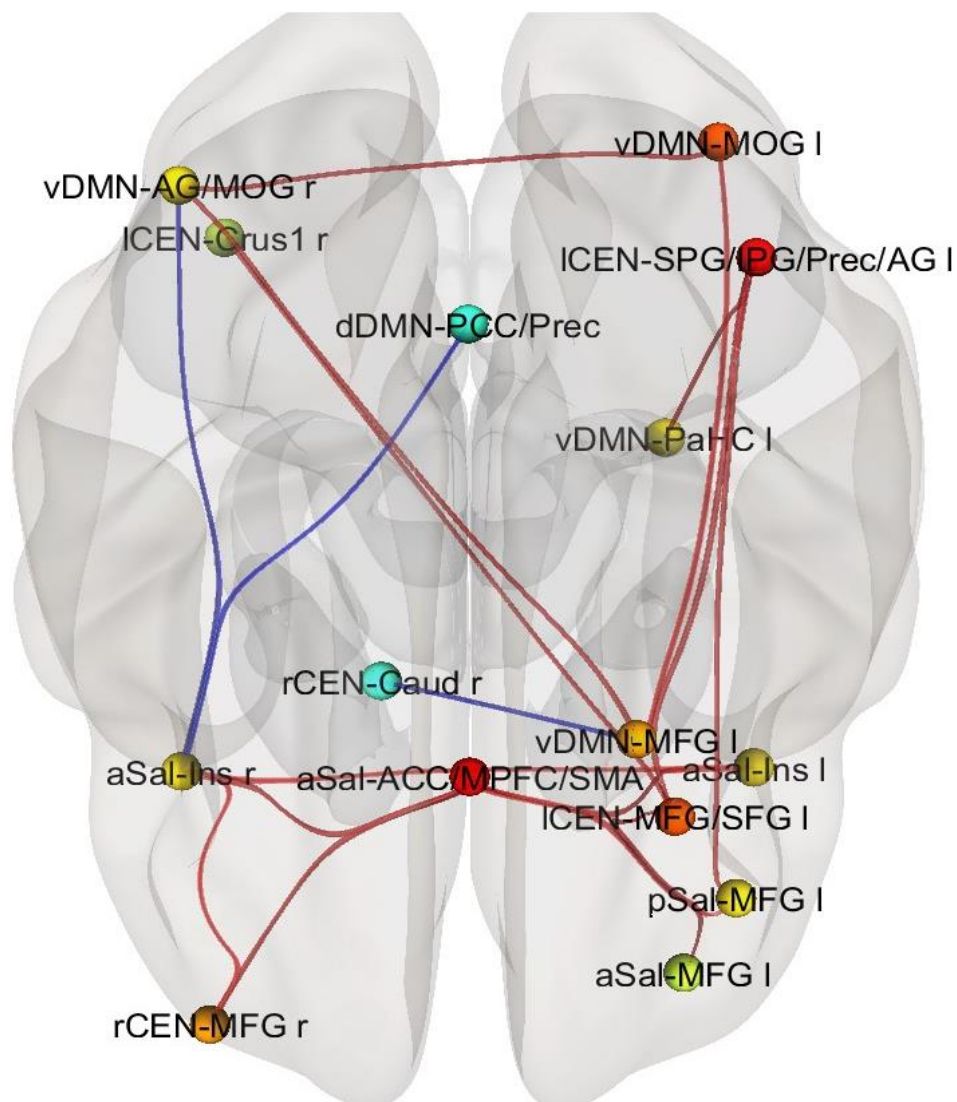


Figure 1b Triple Network FCs of all subjects during task, significantly correlated ROIs, controlling for age, OddballRTave, METs, $p < 0.05$.

3.5 Group Differences between KPs and NKPs for the Triple network ROIs

Group differences (KPs vs. NKPs) in FC at rest and at task between two regions within the triple network are shown in **Figure 2a** and **Figure 2b**. During rs-fMRI, the CONN-toolbox analysis revealed that KPs exhibited a significantly lower FC between the Default Mode Network (DMN) (dorsal MPFC/ACC and ventral MOG1) and the Central Executive network (CEN) (MFG/SFG l) compared with NKPs with all FDR corrected p-values lower than 0.05 (see **figure 2a**) (see **supplementary table**

1).

During the task-based fMRI, KPs had a significantly higher FC between: (1) the ventral DMN (AG/MOG) and the posterior Salience Network (SMG/IPG r), (2) the ventral DMN (MOG l) and the anterior SN (Ins r), (3) the ventral DMN (AG/MOG r) and the right CEN (MFG r), (4) anterior SN (Ins r) and left CEN (Thal l) (5) the posterior SN (SMG/IPR) and the left CEN (Thal l) than the NKPs. (see figure 2b) (see supplementary table 2). KPs also had significantly lower FC between (1) the ventral DMN (PaHC1) and the left CEN (Thal l) and (2) ventral DMN (MOG l) and left CEN (MFG/SFG l) (3) ventral DMN (MFG l) and right CEN (Caud r) (see figure 2b) (see supplementary table 2).

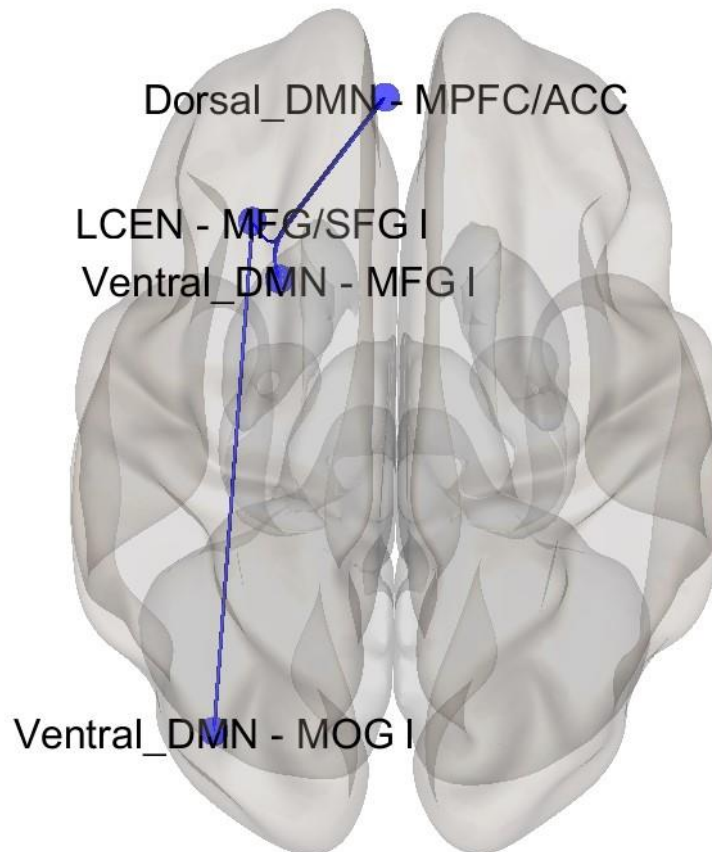


Figure 2a Group difference in triple network FCs during resting state, kendo > non-kendo, significantly correlated ROIs, controlling for age, OddballRTave, METs, $p < 0.05$.

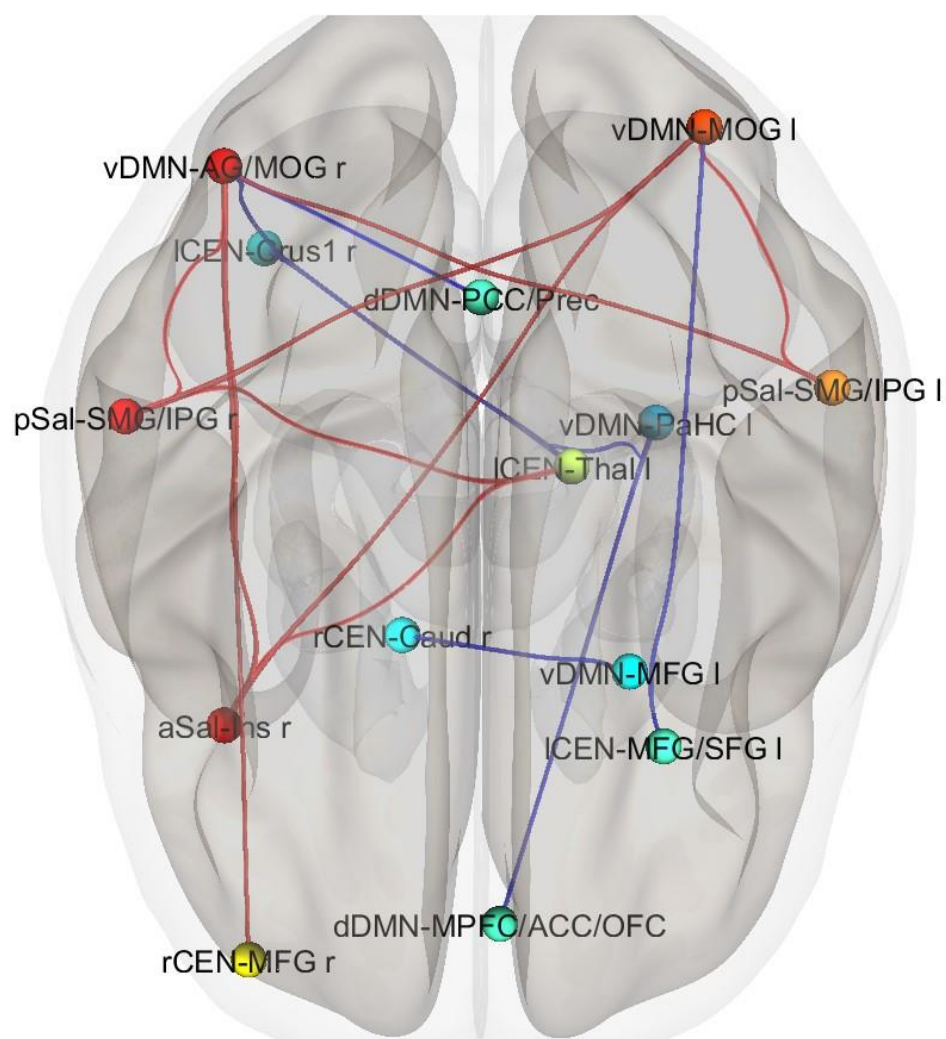


Figure 2b Group difference in triple network FCs during the oddball task, kendo > non-kendo, significantly correlated ROIs, controlling for age, OddballRTave, METs, $p < 0.05$.

3.6 Group differences between KPs and NKPs within each network's ROIs

Regarding the intra-network connectivity, KPs had a lower FC between the MPFC/ACC/OFC- MFG l and MPFC/ACC/OFC - MOG l at resting state within the DMN (**Figure 3a**) but KPs also had a lower FC between the MPFC/ACC/OFC and multiple regions of the DMN (**Figure 3b**) as well as lower FCs between PCC/Pre - PaHC l and PCC/Pre - AG/MOG r during the oddball task phase (**Figure 3b**) (see supplementary table 4).

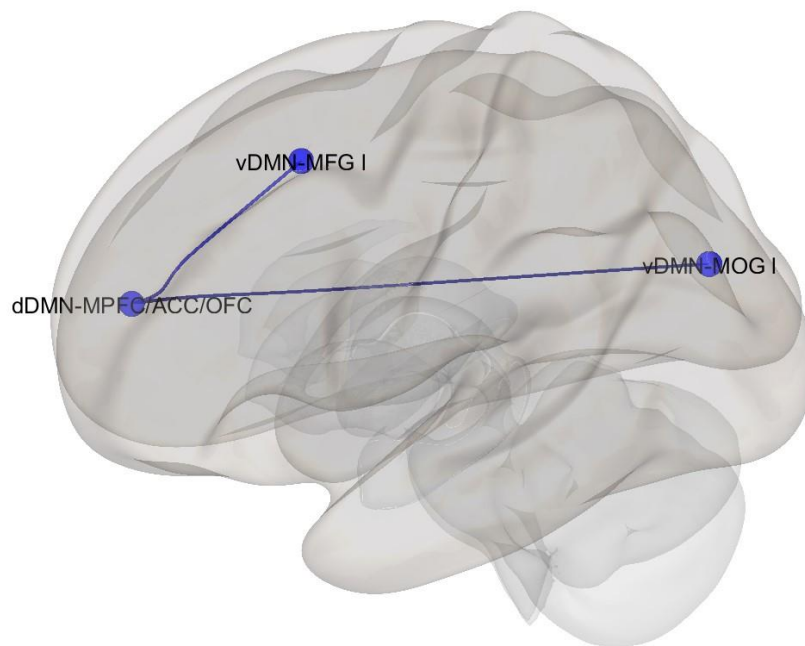


Figure 3a Group difference in intranetwork DMN FCs during resting state, kendo > non-kendo,

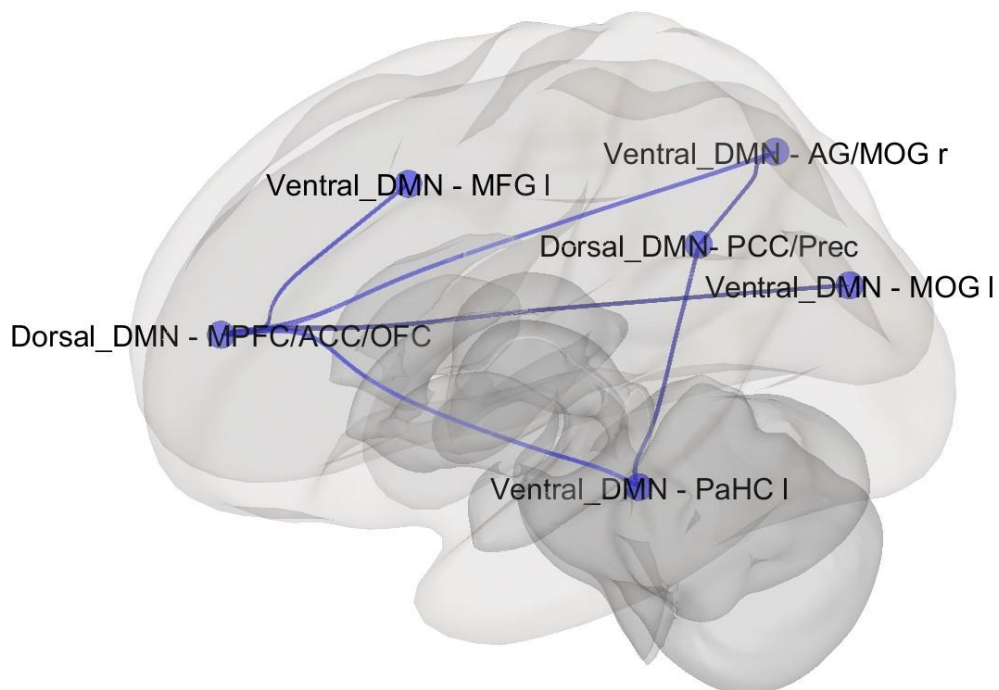


Figure 3b Group difference in intranetwork DMN FCs during oddball paradigm kendo > non-kendo, significantly correlated ROIs, controlling for age, OddballIRTave, METs, $p < 0.05$.

significantly correlated ROIs, controlling for age, OddballRTave, METs, $p < 0.05$.

For the Central Executive Network, there were no remarkable results at rest between the two groups. Whereas, there was higher FC between the Thal l and MFG r ($T = 2.60$, $d = 37$, $p = 0.0363$) but lower FC between Thal l and Crus1 r ($T = -2.56$, $df = 37$, $p = 0.0363$) within the CEN for KPs during the oddball task phase compared to NKPs (Figure 4).

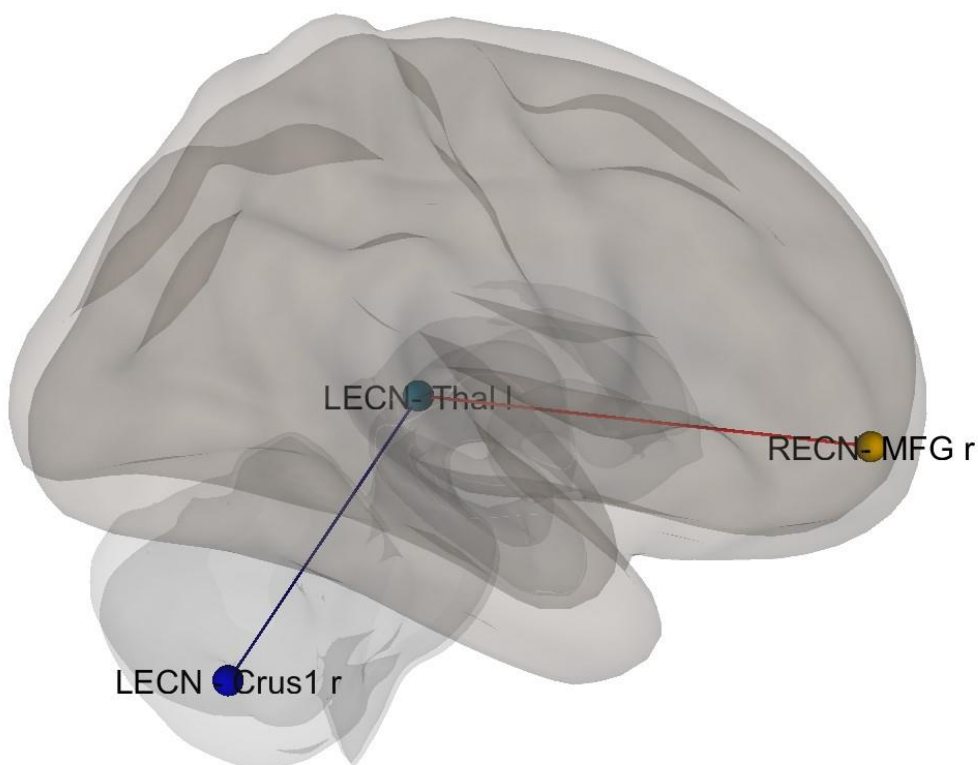


Figure 4 Group difference in intranetwork CEN FCs during oddball task, kendo > non-kendo, significantly correlated ROIs, controlling for age, OddballRTave, METs, $p < 0.05$.

3.7 Triple network ROI FCs without controlling for covariates

In order to justify the inclusion of our covariates we carried out the CONN toolbox analysis once more but this time without controlling for covariates. What we noticed was that for the triple network at rest KPs still had lower connectivity between the DMN (MOG1) and CEN (MFG/SFG l) and during task

still had higher connectivity between the DMN (AG/MOG r) -SN (SMG/IPGr) and SN (SMG/IPGr) – CEN (Thal l) as well as lower connectivity between the CEN (MFG/SFG l) -DMN (MOG l) (see supplementary tables 1 and 2).

For individual networks, within the DMN there was lower connectivity at rest controlling for covariates but there was no difference without controlling for covariates. KPs still had lower connectivity within various regions of DMN compared to NKPs during task (supplementary tables 3 and 4). No differences in the SN at rest or at task. KPs still had no difference at rest in the CEN and during task KPs still had higher connectivity between Thal l and MFG r but did not have lower connectivity between Thal l and Crus1 r (supplementary tables 5 and 6). Overall, our covariates had minimal impact on our results.

Discussion

This is an advanced exploratory study investigating the possible production of mindfulness through basic sensory perceptions and cognitive functions from the perspective of triple network connectivity in highly skilled habitual KP. This was based off the previous evidence “resting versus attentionally driven contrast in motivation” in KPs. This could be useful in a clinical setting as it may provide further understanding of the mechanisms behind possible mental health promotions or cognitive improvements via a modulated form of triple network integrity in conjunction with current therapy practices. Through this method the development of mindful traits such as acceptance, non-judgemental observation and heightened awareness of your surroundings could be possible [24]. Even though mindfulness was not directly measured in this study, it is still relevant to interpret the observed network characteristics in relation to the suggested cultivation of a mindfulness like state fostered through long term kendo training. Kendo’s basis in zen philosophy, emphasises the concept of an unmoved mind

which refers to maintaining composure and awareness during dynamic action. Such a state may encompass this idea of extrospective mindfulness which we defined as an attentional mode directed outward to external stimuli while maintaining inner stability and non-reactivity. If we look at this from a neuroscientific standpoint, this extrospective mindfulness state may correspond to increased salience network engagement and more efficient modulation between executive and default-mode networks, promoting attentional control and reduced self-referential processing. As a result of this, the enhanced SN-CEN and reduced DMN-CEN connectivity observed in Kendo practitioners can be regarded as consistent with this extrospective mindfulness-like attentional mode, rather than direct evidence of mindfulness causation.

A detailed summary of the results of the current study are as follows: (1) We found that there were significant positive correlations between the DMN-SN ($r=0.367$, $p\text{-value} = 0.021$), SN-CEN ($r=0.325$, $p\text{-value} = 0.043$) and verging on significance for the CEN-DMN ($r=0.314$, $p\text{-value} = 0.051$). This supports the theory proposed by Menon [15] which states that task processing requires switching from the DMN to CEN and that this switching is modulated by the SN. (2) Without controlling for covariates, there were no differences seen at rest but KPs had lower overall CEN-DMN connectivity and higher SN-CEN connectivity during task (see tables 2 and 3). (3) When controlling for OddballRTave, there were still no differences during rest but CEN-DMN was approaching significance with a $p\text{-value}$ of 0.052 (see table 4). During task, KPs still had lower FCs in the CEN-DMN and higher FCs in SN-CEN (see table 5) so OddballRTave did not have that much of an effect on our results.

The results of the oddball task illustrate that the group differences found in the triple network FCs was not only due to the differences between two ROIs but can apply to these networks as a whole. This is where the habitual training of KPs is important as the optimisation of their triple network has led to

consistent higher connectivity between the SN-CEN allowing them to respond and react much quicker than their NKP counterparts hence the significantly faster OddballRTave. Furthermore, lower CEN-DMN FCs may mean that KPs maintain this ‘zen-like’ state that we have called extrospective mindfulness for much longer than previously expected even in the absence of a task.

(4) During ROI-ROI rs-fMRI, KPs exhibited a significantly lower FC between ROIs of DMN and CEN compared with NKPs. (5) During the task-based ROI-ROI fMRI, KPs had significantly higher FC between: DMN and SN, SN-CEN as well as the vDMN (AG/MOG r) and the rCEN (MFG r), than NKPs. (6) KPs also had a lower FC between DMN (PaHC1) and CEN (Thal 1). (7) As for the intra-network connectivity, Positive FCs correlations were found in all three networks in both rest and task conditions for all subjects (supplementary figures 1a, 1b, 1c, 2a, 2b and 2c) strengthening the proposed triple network theory. (8) However, when the DMN connectivity of the groups were compared, KPs had lower FC between MPFC/AC and MFG during rest and lower FC between AG/MOG and RSC/PC during task. There were no remarkable results for KPs within the CEN at resting state either but KPs had higher FC between the Thal l and MFG r but lower FC between Thal l and Crusl r within CEN during the oddball task phase.

Lower DMN connectivity during rest and task could be interpreted as a decrease in self-referential processing where as both a decrease and increase in the CEN at task could indicate less switching in KPs (Thal l – Crus r) and increased motor skills (Thal – MFG r). This sustained focus (i.e. less switching) may increase efficiency; thus, a lower cognitive load would be required to complete the task effectively and increase motor skills would lead to faster reaction times.

Our interpretation of results (4) through (8) is that lower resting state FCs between CEN and DMN in

KPs means lower CEN-DMN synchronization in KPs, indicating less switching of CEN to DMN during resting state. A possible interpretation of the results would be more efficient triple network integrity in KPs during resting state. This same result was not seen with the all-subjects analysis as only lower resting state FCs between the SN and CEN were seen as expected. This lends to the idea that lower CEN-DMN synchronisation at rest may be an effect induced through long-term martial arts training. Together with lower MPFC/ACC/OFC-MFG I and MOG I FCs within intra-network DMN, these results would be in line with the potential development of this extrospective mindfulness state due to a more static motivation network connectivity in KPs, suggested by our previous report [7]. Regarding the comparisons between KPs and NKPs during the task fMRI, the same results were not seen when all subjects were analysed as there was lower FCs between DMN-SN, so this idea of sharpened network activity was specific to KPs. This is further exemplified as there were increased SN-CEN FCs, meaning they were able to carry out the task effectively whereas decreased CEN-DMN FCs means they were able to stay focused on the task and were slower at switching back to resting state. Also, the general exercise level between KPs and non-KPs were matched and there was no significant difference between them during the MRI analysis where IPAQ/METS was used as a covariate (see Table 1). This is important as it shows that the difference noted between the two groups is not affected by the degree of exercise.

As mentioned in the introduction the neural correlates of cognitive and sensory perceptions in habitual exercise practitioners compared to the general population is still poorly understood, so we initially hypothesized that KPs are better able to switch their brain networks from resting state to task state (from DMN to CEN) during attention task-based fMRI. In this context the presence of higher SN-CEN connectivity and lower CEN (Thal1) - DMN (PaHC1) FCs support this notion. It is also assumed that there should be a correlation between reaction time and task performance (i.e. quicker the reaction

time the better the task performance) within the DMN-SN but according to our analysis there was no significant association between them. However, salience network activity would still indicate better attention processing in KPs (KP<NKP in OddballRTave as well as IES, although no difference was found in task performance) which is consistent with those in the prior motivation network analyses [7]. However, this could also indicate that individual differences may be a potential influence when it comes to performance as studies by Yao et al found no differences between sports when testing for various cognitive measures [32,33].

Besides standard mindfulness practices, mindfulness training through sport can still help since athletic fitness can possibly mitigate inappropriate connections between the SN-DMN during task performance [34,35,36]. The reason behind this is still unknown but a possible method of action could be via the improvement of CEN dynamics like executive functioning that occur as a result of exercise [37]. For martial arts specifically, karate has shown improved corticospinal excitability whereas taekwondo showed better motor cortex function. Adaptations such as this, were seen to be chronic, not acute, especially for the older practitioners [38]. Our results using kendo may also lend to this idea because a recent fMRI study has indicated an increase in FC between the DMN-SN as well as the SN-CEN in individuals who underwent a 31-day mindfulness meditation training course compared to control [17]. Such changes may further sustain the mind-body unity that we think give KPs the advantage over NKPs, alongside the breathing techniques that help with initial mind and body arrangement. The type of breathing techniques employed during kendo training may therefore be a vital step of this process [39]. One such technique often employed is that of diaphragmatic breathing. This is where the diaphragm is contracted, belly expanded and a deepening of inhalation and exhalation [40]. This is effective because studies have shown it can help produce special rhythmic movements such as those seen in martial arts, effectively enhance emotions and lead to a reduction in stress, depression and anxiety [41,42,43,44]. Therefore, these practices have the potential to be used

as a tool for mental health promotion to the general public.

Mental health practitioners and policy makers could present these findings and any other corroborating evidence to hospitals and encourage them to set up mindfulness related rehabilitation programmes at daily clinical practices for individuals that have psychiatric illnesses, this can include sports like kendo. There is already a precedent for this through activities such as yoga which was initially seen as a fad but is now being recognised as a valuable psychiatric treatment [45,46,47].

There are a few limitations that should be considered in the current study. Firstly, the sample involved only male participants. The reason for this is that the majority of kendo players are still men and the final number of people who chose to participate in this study were also only men. When considering the presence of female kendo players or martial arts players throughout the world, further studies are needed to generalize the results of this study with regards to gender-balance so a more holistic perspective can be achieved. One of the major limitations was that the sample size was relatively small since there were only thirty-eight participants and this may impede the reproducibility of our findings so future works should be conducted with a larger sample size to increase robustness. As this was a cross-sectional study, it is difficult to establish causality so a longitudinal study may also be necessary to further clarify any causal relationship between kendo practice and FC changes which has been suggested here through the KPs inclusion criteria and by comparing with other sports in the future we can further exemplify any differences seen here. Secondly, the degree of mindfulness was not measured so in the future having the participants fill out a mindfulness-based questionnaire such as the FFMQ (Five Facet Mindfulness Questionnaire) [48] could be valuable in order to further verify this relationship. Thirdly, in this study specifically, we did not examine the differences between any other sport and kendo, therefore, further studies are needed to clarify if there are any specific effects on brain network integrity. While we found no difference in METs between KPS and NKPs, we did not control for cardiovascular variables like heart rate or blood pressure in the current study even

though they are important modulators of rsfMRI connectivity and task-related responses so this should be noted as a further limitation. The technical limitations of the programmes we are using also mean that we are only able to see correlations between these areas of the triple network and not the directionality which would be important in confirming the switching mechanism. As only reaction times were reported more complex and comprehensive cognitive measures need to be implemented in the future in order to further verify our hypothesis.

Conclusion

In conclusion, we examined how habitual kendo training can lead to the development of a mindfulness-like state by focusing on the connectivity of the triple network during resting state and an attention-related auditory oddball task. Overall, moderate positive correlation between all areas of the triple network were found and the ANOVAs showed a significant difference between the two groups for task FCs, particularly in the SN-CEN and CEN-DMN. For our chosen ROIs, KPs had lower FCs between CEN-DMN ROIs during resting state but had higher DMN-SN and SN-CEN FCs as well as higher vDMN (AG/MOG r) - rCEN (MFG r) FCs during the attention-related task. KPs also had lower CEN-DMN FCs during task too. Our results suggest that higher SN-CEN FCs and lower CEN-DMN FC could indicate increased triple network integrity in KPs presumably because of the habitual trainings which in turn contributes to the mind-body unity that may produce this extrospective mindfulness-like state. However, an alternative explanation could be that due to the consistent and intense nature of kendo training there is also potential for a sustained reduction in base line arousal as a byproduct which contributed to these results rather than increased efficiency. Further studies with a larger sample size and a longitudinal study design are needed to verify the present findings. Habitual training which is substantiated in martial arts might be clinically applicable to a wide range of health promoting programs as an alternative or in conjunction with current therapy practices.

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545

546 Abbreviations key:

547 vDMN- Ventral Default Mode Network

548 dDMN – Dorsal Default Mode Network

549 aSal – Anterior Salience network

550 pSal – Posterior Salience Network

551 ICEN- Left Central Executive Network

552 rCEN – Right Central Executive Network

553 AG r– Angular Gyrus right

554 MOG1 – Medial Occipital Gyrus

555 PCC – Posterior Cingulate Cortex

556 Prec – Precuneus

557 SFG – Superior Frontal Gyrus

558 MFG – Medial Frontal Gyrus

559 PAHC r – Parahippocampal Cortex right

560 MPFC – Medial Prefrontal Cortex

561 IFG – Inferior Frontal Gyrus

562 OFG – Orbital Frontal Gyrus

563 Caud r – Caudate nucleus right

564 Thal l – Thalamus, left

565 Crus1 r – Cerebellum, right

566 ACC – Anterior Cingulate Cortex

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Statements and declarations

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Author contributions

Michael Spantios did the data recording, data analysis, wrote the manuscript, edited the manuscript, and made all of the figures and tables. Tsukasa Ueno was responsible for MRI acquisition and preprocessing, recruitment of participants and assessment of general physical activity and other life habits. Mami Shibata did initial data analysis. Naoya Oishi produced MATLAB scripts that were used in the functional connectivity analysis and connectivity analysis. Morio Aki helped to revise the manuscript. Toshiya Murai overlooked the project and helped to revise the manuscript. Hironobu Fujiwara was responsible for conception and design of the project, funding and also helped to revise the manuscript.

Data availability

This data is available upon request by contacting the corresponding author.

Conflict of interest

The authors have declared that there were no conflicts of interest present in this study be it financial or otherwise. The results of the study are presented clearly, honestly, and without fabrication, falsification, or inappropriate data manipulation.

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