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Research report

Sensorimotor network hyperactivity and impaired psychomotor performance associated with cumulative occupational stress in firefighters

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ABSTRACT

Firefighters face chronic occupational stressors including trauma exposure, sleep disruption, and substantial physical demands that can compromise brain function and cognition. Despite increasing concern regarding stress-related cognitive decline in this population, limited evidence is available on whether occupational stress is associated with alterations in resting-state networks (RSNs) or whether such neural changes relate to cognitive outcomes. This study investigated occupational stress-related alterations in functional connectivity (FC) across major RSNs and examined their associations with cognitive performance in firefighters. Ninety-eight actively employed firefighters and 98 demographically matched non-firefighter controls underwent resting-state functional magnetic resonance imaging. RSN-specific FC was derived using independent component analysis. Group comparisons identified significantly higher FC within the sensorimotor network (SMN) in firefighters relative to controls (family-wise error-corrected $P < 0.05$). Within the firefighter group, both longer cumulative duration of emergency duties ($\beta = 0.45$, $P = 0.013$) and higher alcohol use levels ($\beta = 0.37$, $P = 0.003$) were independently associated with increased SMN connectivity. Moreover, SMN hyperconnectivity was significantly correlated with poorer psychomotor performance ($\beta = -0.19$, $P = 0.023$), indicating potential behavioral consequences. These findings provide evidence that chronic occupational stress and maladaptive coping behaviors such as alcohol misuse may contribute to functional reorganization of the SMN in firefighters which may be linked to diminished psychomotor efficiency. The results highlight a potential neurobiological mechanism through which occupational stress influences cognitive functioning and underscore the need for early identification of at-risk individuals and targeted interventions to mitigate cumulative stress burdens in this vulnerable occupational group.

1. Introduction

Firefighters are consistently exposed to a wide range of occupational stressors throughout their careers, including repeated exposure to traumatic incidents, sleep disturbances, heat stress, and fatigue, which collectively increase vulnerability to stress-related mental health problems (Kim et al., 2018; Wagner et al., 2021). Longer service duration has also been associated with a higher burden of mental health conditions in this population, indicating cumulative effects over time (Wolffe et al., 2023). In addition, firefighters demonstrate reduced cognitive performance in specific domains such as psychomotor function and show an increased risk of cognitive disorders (Mann et al., 2025). However, due to stigma and limited access to mental health services, many firefighters rely on maladaptive coping strategies such as excessive alcohol consumption rather than seeking professional care, which may further exacerbate both mental health and cognitive difficulties (Karnick et al., 2022; Kim et al., 2018). These unique combinations of occupational demands, maladaptive coping behaviors, and underutilization of mental

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health support may impose a significant burden on brain function in firefighters. Given that mental health problems and cognitive deficits can impair job performance and jeopardize the safety of both firefighters and the public, early identification of at-risk individuals and long-term professional support are critical for maintaining the health and operational readiness of this vulnerable workforce.

Neurobiological investigations that link occupational stress to clinical consequences are essential to better understand the impact of occupational stress on brain function and behavior, and to inform the development of targeted interventions. However, only a limited number of neuroimaging studies, including our own, have examined such mechanisms in firefighters. Prior functional magnetic resonance imaging (fMRI) studies have documented altered resting-state functional connectivity (FC) or task-evoked activity and reported associations with clinical characteristics (Jeong et al., 2019; Kim et al., 2022; Lee et al., 2022; Reynaud et al., 2013, 2015). Nevertheless, characteristics of large-scale RSNs, which are intrinsic neural systems supporting a wide range of emotional, cognitive, and behavioral functions, remain underexplored in firefighters because earlier studies predominantly relied on seed-based analytic approaches (Jeong et al., 2019; Kim et al., 2022; Lee et al., 2022).

The present study aimed to examine FC within networks of interest (NOIs), including the default mode network (DMN), salience network (SN), frontoparietal network (FPN), and SMN, which may be closely related to occupational demands experienced by firefighters such as sustained stress responses, emotional and cognitive regulation, and physical performance (Menon, 2023; Zhang et al., 2020). To focus specifically on the neural correlates of occupational stress, only firefighters without current neurological or psychiatric disorders were included. For any identified alterations in RSN connectivity, we assessed associations with cumulative emergency service duration and levels of alcohol use to explore potential contributing factors. In addition, associations between altered FC and psychomotor performance were evaluated to determine possible behavioral consequences.

2. Methods

2.1. Participants

The cohort consisted of 98 professionally active Korean firefighters and 98 demographically matched healthy non-firefighter controls, as described in our previous study (Jeong et al., 2019). All firefighters had been employed for at least 6 months and were routinely exposed to chronic occupational stress during their duties. Participants were excluded if they had a major medical illness including neurological or psychiatric disorders; were taking current psychotropic medications; had a history of mild traumatic brain injury; or had contraindications to MRI. All individuals provided written informed consent, and the study protocol was approved by the Institutional Review Board of Ewha Womans University.

2.2. Clinical and cognitive assessment

South Korean firefighters are assigned a primary role at each station and rotate across stations throughout their careers (Kim et al., 2018). Emergency service duration was defined as the cumulative period of fire suppression, rescue operations, and emergency medical services, excluding administrative and support roles. Of the 98 firefighters, 81 (82.7%) had engaged in emergency service duties for at least one year (mean ± SD, 8.4 ± 7.6 years), whereas 17 (17.3%) had no prior emergency service experience.

Alcohol use was evaluated using the Alcohol Use Disorders Identification Test (AUDIT) (Saunders et al., 1993). AUDIT data were available for 85 firefighters and 88 non-firefighter controls.

Psychomotor performance was assessed using the Grooved Pegboard Test (GPT) (Heaton et al., 2021). Participants inserted 25 metal pegs into keyhole-shaped slots using one hand at a time. The test was administered separately for the dominant and non-dominant hands, and the completion time for each hand was recorded, with a maximum time limit of 300 s. For statistical analysis, completion times for each hand were converted to z-scores based on the mean and standard deviation of the non-firefighter group, averaged, and reversed so that higher scores indicated better performance. Complete GPT data were available for 94 firefighters and 66 non-firefighter controls.

2.3. MRI data acquisition and processing

Brain MRI data were acquired using a 3.0 Tesla Philips Achieva scanner (Philips Medical Systems, Best, The Netherlands) equipped with a 32-channel head coil. High-resolution three-dimensional T1-weighted structural images were acquired using the following parameters: repetition time (TR) = 7.4 ms, echo time (TE) = 3.4 ms, flip angle (FA) = 8°, field of view (FOV) = 220 × 220 mm^2, and voxel size = 0.86 × 0.86 × 0.86 mm^3. Resting-state functional MRI scans were obtained using a gradient-echo echo-planar imaging (EPI) sequence with TR = 2000 ms, TE = 21 ms, FA = 76°, FOV = 220 × 220 mm^2, voxel size = 3.44 × 3.44 × 3.44 mm^3, 38 slices, and 200 volumes. During scanning, participants remained awake with their eyes closed, avoided directed thought, and allowed their minds to wander.

Resting-state fMRI data were preprocessed using the FMRIB Software Library (FSL, version 6.0.4). The preprocessing pipeline included rigid-body realignment for motion correction (MCFLIRT), brain extraction (BET), and high-pass temporal filtering (cutoff 0.01 Hz). Single-subject independent component analysis (ICA) was conducted using FSL Multivariate Exploratory Linear Optimized Decomposition into Independent Components (MELODIC) version 3.15 (Beckmann and Smith, 2004). Motion and physiological noise components were then identified and removed using FSL's ICA-based Xnoiseifier (FIX) with a classifier trained on manually classified components (Griffanti et al., 2014; Salimi-Khorshidi et al., 2014). Cleaned fMRI data were coregistered to the corresponding T1-weighted image and nonlinearly registered to Montreal Neurological Institute (MNI) 152 standard space, followed by resampling to 4-mm isotropic resolution and spatial smoothing with a Gaussian kernel of 5-mm full width at half maximum.

Head motion was quantified using framewise displacement (FD) (Power et al., 2012). There were no significant group differences in mean FD between firefighters (mean ± SD, 0.11 ± 0.05 mm) and non-firefighter controls (0.10 ± 0.05 mm, $t = 1.05$, $P = 0.296$).

2.4. Functional connectivity analysis

Group ICA was conducted on the preprocessed fMRI data from all participants to identify coherent intrinsic networks. This data-driven approach decomposed the four-dimensional fMRI data into spatially independent components and their associated time series. Twenty-five independent components were extracted, of which 12 were classified as biologically meaningful RSNs based on spatial patterns consistent with established network templates (Fig. 1). Among these, the DMN, SN, left and right FPN, and SMN were selected as networks of interest. Each network map was thresholded at $z > 3.0$ to generate a mask, and dual regression was applied to obtain subject-specific spatial maps and time series for each network. FC within each network was estimated as voxel-wise parameter estimates (PEs).

Voxel-wise between-group differences in FC were assessed for each network using general linear modeling with age, sex, and mean FD included as covariates. Statistical inference was conducted using nonparametric permutation testing (5,000 permutations) with threshold-free cluster enhancement (TFCE) (Smith and Nichols, 2009). Results were considered significant at a family-wise error-corrected threshold of $P < 0.05$. No additional multiple-comparison correction was applied across the a priori selected networks of interest. To ensure robustness and avoid reporting small isolated clusters, only clusters

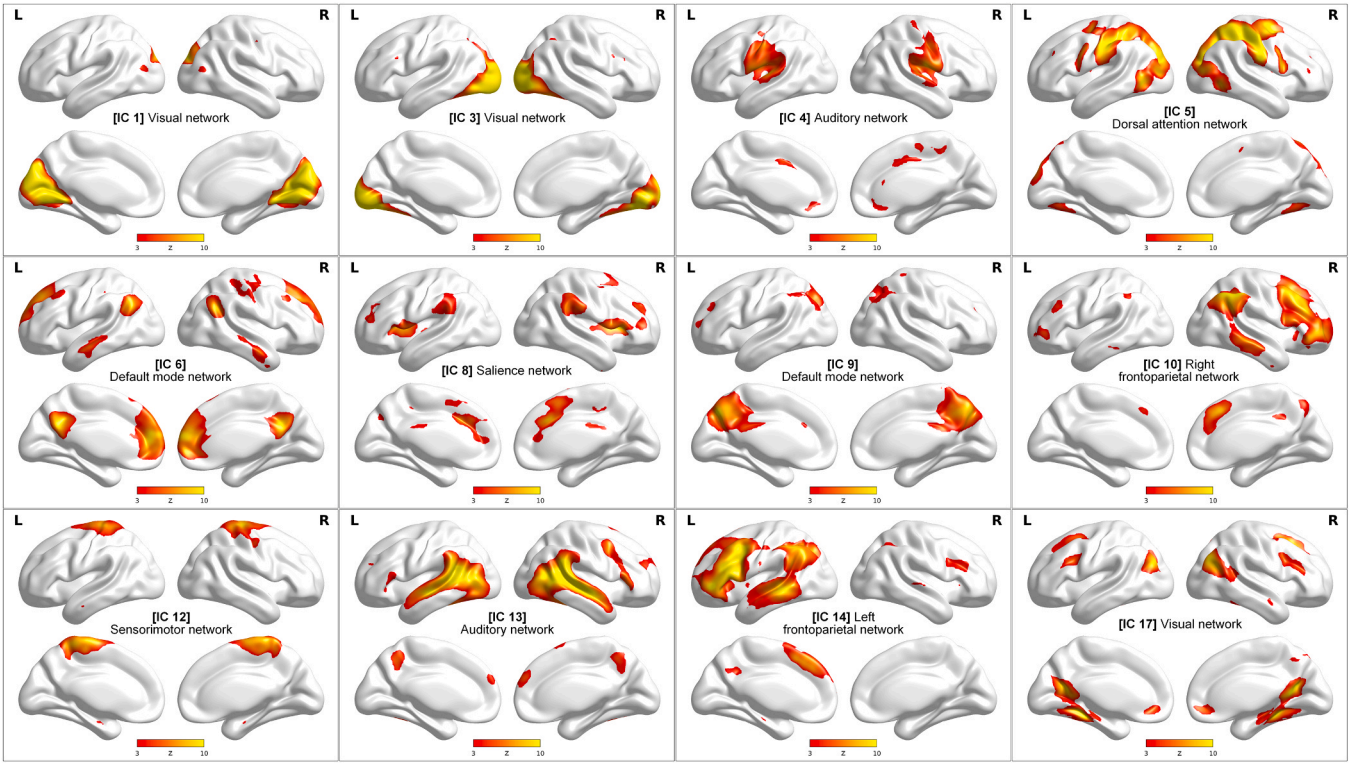


Fig. 1. Resting-state networks identified using independent component analysis. Of the 25 ICs extracted, 12 were classified as biologically meaningful resting-state networks. Spatial maps were thresholded at $z > 3.0$, and the color bars represent voxel-wise z values. Component numbers were assigned in descending order of explained variance. IC, independent component.

comprising at least 30 contiguous voxels were included as significant findings (Antonenko et al., 2013; Yan et al., 2025). For each significant cluster, mean PE values were extracted for subsequent statistical analyses.

To provide a more integrated perspective of the functional organization, we additionally examined inter-network FC among the predefined NOIs. Detailed methodologies for the inter-network connectivity analysis using the FSLNets toolbox (v0.6) are described in the Supplementary Methods.

2.5. Statistical analysis

Demographic and clinical characteristics were compared between the firefighter and non-firefighter groups using independent *t*-tests, chi-square tests, or Fisher's exact tests, as appropriate. Psychomotor performance scores were compared between groups using analysis of covariance, adjusting for age, sex, and education level.

To examine the potential effects of cumulative emergency duty exposure on altered FC in firefighters, multiple linear regression analyses were conducted to evaluate the relationship between total duration of emergency service and FC among those with emergency duty assignments throughout their careers. Age, sex, and mean FD were included as covariates. The analyses were repeated using total duration of employment as a firefighter in place of cumulative emergency service duration to determine whether connectivity alterations were specifically attributable to emergency duty exposure rather than general service length.

The effects of alcohol use on FC were examined using separate multiple linear regression models for each group. Independent contributions of cumulative emergency duty exposure and alcohol use were further evaluated in firefighters by including both predictors in the same model. Age, sex, and mean FD were controlled in all alcohol-related analyses.

Associations between altered FC and psychomotor performance were assessed using multiple linear regression models with the GPT score as the dependent variable and age, sex, education level, and mean FD included as covariates. To further examine the relationships among occupational stress exposure or alcohol use, SMN connectivity, and psychomotor performance, we performed exploratory mediation analyses. Two separate models were constructed to test whether SMN connectivity mediates the effects of (1) cumulative emergency duty duration and (2) AUDIT scores on GPT scores. These analyses were conducted within the firefighter group. Age, sex, and mean FD were included as covariates for both the mediator and the dependent variable, with education level additionally controlled for the dependent variable. To evaluate the indirect effects, we employed a non-parametric bootstrapping approach with 5,000 resamples to generate 95% confidence intervals (CIs).

The statistical significance threshold was set at two-tailed $P < 0.05$. All analyses were performed using Stata SE version 16.0 (StataCorp, College Station, TX, USA).

3. Results

3.1. Participant characteristics

Participant characteristics are summarized in Table 1. The mean age was approximately 41 years, and the majority of participants in both groups were male. There were no significant between-group differences in age ($t = 0.26$, $P = 0.795$), sex ($\chi^2 = 0.07$, $P = 0.788$), education level ($\chi^2 = 2.09$, $P = 0.148$), or handedness ($\chi^2 = 1.09$, $P = 0.297$). Among firefighters, the mean total duration of employment was 13.7 ± 8.1 years, consisting of 8.4 ± 7.6 years in emergency duties and 4.6 ± 6.9 years in non-emergency roles. AUDIT scores were significantly higher in firefighters than in controls ($t = -2.03$, $P = 0.044$), whereas current smoking prevalence did not significantly differ between groups ($\chi^2 =$

Table 1
Participant characteristics.

Characteristics	Firefighters ($n = 98$)	Non-firefighters ($n = 98$)	P
Age, years	40.9 (7.8)	41.3 (10.4)	0.795
Male, *n* (%)	90 (91.8%)	91 (92.9%)	0.788
Higher education[a]	75 (76.5%)	83 (84.7%)	0.148
Right handedness	88 (89.8%)	92 (93.9%)	0.297
Duration of firefighter duties, years	13.7 (8.1)	-	-
Emergency response, years	8.4 (7.6)	-	-
Non-emergency response, years	4.6 (6.9)	-	-
AUDIT scores	9.8 (7.3)[b]	7.8 (5.8)[c]	0.044
Current smoker, *n* (%)	21 (24.7%)[b]	30 (34.1%)[c]	0.176

Data are presented as mean (standard deviation) or number (%).
AUDIT, Alcohol Use Disorders Identification Test.
[a] College degree or higher
[b] $n = 85$
[c] $n = 88$

1.83, $P = 0.176$).

3.2. Group differences in functional connectivity of resting-state networks

Voxel-wise group comparisons were performed for each RSN of interest, including the DMN, SN, left and right FPN, and SMN. A significant cluster within the precentral and postcentral gyri of the SMN showed greater FC in firefighters than in non-firefighter controls (peak $t = 5.04$, cluster size = 4,650 voxels, peak MNI coordinates = [−30, −32, 48]; Fig. 2). No significant between-group differences were observed in the other networks, indicating a network-specific alteration. Individual mean parameter estimate values were extracted from the significant cluster for subsequent correlation analyses.

In the exploratory inter-network connectivity analysis among the 15 unique pairs of NOIs, no connections survived the false discovery rate (FDR)-correction ($P < 0.05$). However, trend-level reductions in connectivity were observed in firefighters compared to controls between the DMN and right FPN, and between the right FPN and SMN (both FDR-corrected $P = 0.071$). Detailed statistical results for all inter-network comparisons are presented in Supplementary Table 1.

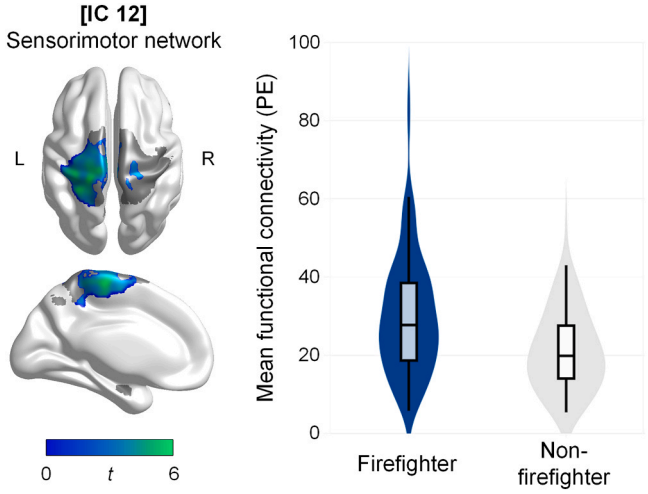


Fig. 2. Increased functional connectivity in the sensorimotor network in firefighters. The cluster showing significant between-group differences in functional connectivity (blue to green color scale) is overlaid on the sensorimotor network mask (gray). The color bar indicates voxel-wise t values. Mean functional connectivity values extracted from the significant cluster are displayed for each group using violin plots combined with box plots. IC, independent component; L, left; PE, parameter estimate; R, right.

3.3. Effects of emergency duty exposure and alcohol use on functional connectivity

Among firefighters assigned to emergency duties, cumulative years of emergency service were positively associated with increased FC within the SMN cluster identified in the group analysis ($n = 81$, $\beta = 0.39$, $P = 0.025$; Fig. 3A). In contrast, total service duration of firefighting employment was not associated with SMN connectivity ($n = 98$, $\beta = 0.30$, $P = 0.298$), suggesting that the observed connectivity enhancement may be specifically linked to emergency duty exposure.

Higher AUDIT scores were also significantly associated with increased SMN connectivity in firefighters ($\beta = 0.25$, $P = 0.028$; Fig. 3B), whereas no significant association was observed in non-firefighter controls ($\beta = 0.11$, $P = 0.205$).

In a multiple linear regression model including both cumulative emergency duty duration ($\beta = 0.45$, $P = 0.013$) and AUDIT scores ($\beta = 0.37$, $P = 0.003$), each predictor remained significantly and positively associated with SMN connectivity, indicating independent contributions of occupational stress exposure and alcohol use.

3.4. Effects of altered sensorimotor functional connectivity on psychomotor function

Psychomotor performance scores on the GPT in firefighters ($n = 94$, $z = -0.49 \pm 0.96$) were lower than those of non-firefighter controls at a trend level ($n = 66$, $z = 0.00 \pm 0.92$, $t = -1.84$, $P = 0.068$) after adjusting for age, sex, and education level.

FC within the SMN cluster was negatively associated with psychomotor performance in firefighters ($\beta = -0.19$, $P = 0.023$), whereas no significant association was observed among non-firefighter controls ($\beta = 0.05$, $P = 0.753$; Fig. 4).

Furthermore, mediation analyses showed that the indirect effects of emergency duty duration ($b = -0.010$, $P = 0.104$, bootstrapped 95% CI = −0.022–0.002) and AUDIT score ($b = -0.007$, $P = 0.121$, bootstrapped 95% CI = −0.016–0.002) on psychomotor performance via SMN connectivity were not statistically significant (Supplementary Table 2).

4. Discussion

In this study, we investigated the relationships among chronic occupational stress, alcohol use, resting-state brain network connectivity, and psychomotor performance in firefighters. The principal finding was that firefighters demonstrated significantly higher FC within the SMN compared with non-firefighter controls. Within the firefighter group, both longer cumulative exposure to emergency duty and higher levels of alcohol use were independently associated with increased SMN connectivity. Notably, this SMN hyperconnectivity was further associated with poorer psychomotor performance on a fine motor task. Taken together, these findings suggest that chronic job-related stress and maladaptive coping behaviors may contribute to functional alterations within the SMN that manifest as subtle neurocognitive deficits, even in firefighters who are otherwise healthy and without clinical diagnoses.

Although prior neuroimaging research on stress and trauma has largely focused on emotion regulation circuitry involving the amygdala and prefrontal cortex, the present results highlight a central role for the SMN. The observed SMN hyperconnectivity aligns with previous work demonstrating neuroplastic changes in RSN during prolonged stress exposure and partial recovery (Soares et al., 2013a, 2013b). In these studies, stressed individuals exhibited increased FC across specific networks, including the SMN, and these alterations did not fully normalize over time. In addition, traumatic stress and sleep disturbance—both common occupational exposures among firefighters—have been linked to heightened sensorimotor connectivity (Bai et al., 2022; Shaw et al., 2023). Elevated SMN connectivity may represent a state of heightened motor and sensory readiness that supports rapid stress responses,

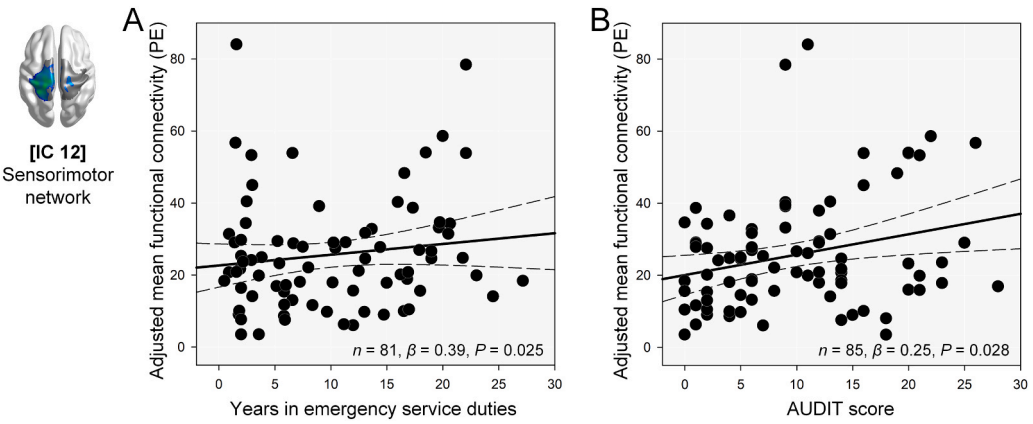


Fig. 3. Associations between altered sensorimotor functional connectivity and (A) cumulative emergency duty duration and (B) AUDIT scores in firefighters. Adjusted functional connectivity (PE) values denote estimates controlling for age, sex, and mean framewise displacement. Solid lines indicate the fitted regression lines, and dashed lines represent 95% confidence intervals. AUDIT, Alcohol Use Disorders Identification Test; FD, framewise displacement; IC, independent component; PE, parameter estimate.

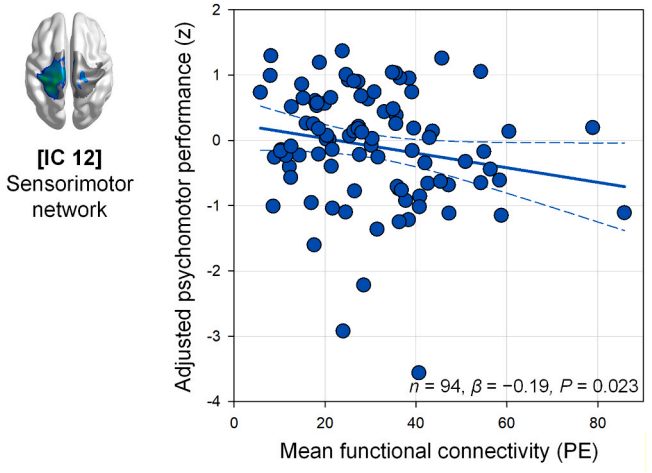


Fig. 4. Association between altered functional connectivity in the sensorimotor network and psychomotor performance in firefighters. Psychomotor function scores were adjusted for age, sex, mean framewise displacement, and education level, where higher values indicate faster performance. Solid lines represent fitted regression lines, and dashed lines indicate 95% confidence intervals.FD, framewise displacement; PE, parameter estimate.

particularly those involved in preparing fight-or-flight behaviors (Pijlman et al., 2003). This interpretation converges with evidence of impaired sensorimotor gating under stress (Grillon and Davis, 1997). Accordingly, SMN hyperconnectivity in firefighters may reflect a state of chronic physical readiness or hypervigilance. Given the demands of the profession, which require instantaneous responses to life-threatening emergencies, sustained upregulation of the sensorimotor system may strengthen functional coupling within these regions even during rest. This interpretation is consistent with conceptualizations of "embodied stress," in which traumatic experiences become encoded not only as cognitive representations but also as somatic and motor patterns (Tsur et al., 2018; Fleming et al., 2024).

The specific association between SMN connectivity and cumulative emergency duty duration—rather than total length of service—emphasizes the cumulative impact of trauma exposure (Kim et al., 2018). This dose-dependent pattern is consistent with the allostatic load framework, in which repeated physiological adaptation to stressors results in progressive neural and systemic strain. Clinically, these findings raise the possibility that SMN hyperconnectivity could function as an objective neural marker of cumulative stress burden in firefighters, detectable before the development of post-traumatic stress disorder or significant functional decline. Interventions that emphasize somatic regulation, including biofeedback and sensorimotor psychotherapy, may offer particular benefit by helping individuals reduce chronic bodily tension and restore neural efficiency.

Higher levels of alcohol use, independent of cumulative emergency duty exposure, were also associated with increased FC within the SMN in firefighters. Previous studies have reported alcohol-related increases in FC in the SMN among healthy individuals, accompanied by reduced attention and slower reaction times (Ochi et al., 2022). The underlying mechanism may relate to the effects of alcohol on GABAergic neuromodulation, which suppresses neural firing yet paradoxically results in increased FC (Ochi et al., 2022). Elevated sensorimotor connectivity has also been observed in individuals with alcohol use disorder, particularly involving subcortical reward regions and frontal cortical networks (Maleki et al., 2022). These findings underscore the importance of early screening and intervention for excessive alcohol use in firefighters to mitigate potential neural consequences before the progression to alcohol use disorder.

Firefighters showed a trend-level reduction in GPT performance relative to controls. Psychomotor functioning has been recognized as one of the cognitive domains most susceptible to occupational stress in firefighters (Mann et al., 2025), and may be negatively influenced by poor sleep quality, heat stress, cardiovascular strain, and fatigue (Frost et al., 2021; Hancock et al., 2007). Although the present results are generally consistent with the existing literature, the smaller sample size available for the psychomotor analysis may have limited the statistical power to detect significant group differences. Given that firefighters perform complex and physically demanding tasks in unpredictable and hazardous environments, psychomotor efficiency remains a critical cognitive capability for operational performance and safety.

Beyond intra-network alterations, additional analyses of inter-network connectivity revealed trend-level reductions in the coupling between the DMN, FPN, and SMN. Although these findings did not survive FDR correction, they raise the possibility that altered functional organization in firefighters may extend beyond within-network connectivity. However, the present data did not support robust inter-network alterations, and these findings should therefore be interpreted cautiously.

The observed association between increased SMN connectivity and lower psychomotor performance indicates potential neural mechanisms underlying motor inefficiency in firefighters. This finding aligns with prior work demonstrating negative associations between SMN connectivity and fine motor skills in healthy adults (Linke et al., 2020; Solesio-Jofre et al., 2014). Moreover, age-related increases in

sensorimotor connectivity accompanied by impaired motor function have been documented, suggesting that vulnerability of the SMN to neural inefficiency may become more prominent with aging (Solesio-Jofre et al., 2018, 2014). Clinical neuroimaging studies have similarly reported that increased SMN connectivity is associated with psychomotor slowing in individuals with psychosis and with sensory and motor impairments in multiple sclerosis (Lefebvre et al., 2024; Strik et al., 2021). Under normal conditions, efficient movement execution relies on precise and selective network coupling that strengthens task-relevant pathways while suppressing irrelevant neural signals to maintain a high signal-to-noise ratio and accurate motor output. Both in healthy individuals and in patients with psychomotor slowing, reduced cortical inhibition has been linked to elevated resting-state SMN connectivity (Lefebvre et al., 2024). In this context, the sensorimotor hyperconnectivity observed in firefighters may reflect maladaptive and inefficient network reorganization rather than enhanced functional performance, characterized by diminished inhibitory control, increased neural noise, and compromised command fidelity, ultimately manifesting as slower and less accurate fine motor responses (Lefebvre et al., 2024; Solesio-Jofre et al., 2014; Strik et al., 2021). While we explored the mediating role of SMN connectivity between occupational stressors and psychomotor performance, the formal indirect effects were not statistically significant. This lack of significance may be partly attributed to limited statistical power in the subset analyses. Future larger-scale studies are needed to further elucidate these mechanistic pathways.

Some limitations should be taken into account when interpreting these findings. First, the cross-sectional design limits the ability to establish causal relationships between occupational stress exposure, alterations in FC, and cognitive outcomes. Second, although firefighters experience multiple forms of occupational stress, the relative contributions of distinct stressors to neural alterations were not disentangled in the present study. Future longitudinal research incorporating comprehensive quantification of diverse occupational exposures will be necessary to determine both independent and interactive effects of specific stressors on brain networks and associated behavioral outcomes. Third, the present findings may not generalize to firefighters with neuropsychiatric conditions such as depression or post-traumatic stress disorder, as the sample was restricted to individuals without clinical diagnoses or overt functional impairment in order to isolate the effects of occupational stress in otherwise healthy firefighters.

In conclusion, this study provides evidence that chronic occupational stress associated with emergency duty is linked to altered FC within the SMN in firefighters, which may contribute to reduced psychomotor performance. Furthermore, elevated alcohol use may also play a contributory role in these neural and behavioral changes. These findings highlight the importance of early detection and targeted support to mitigate the cumulative effects of occupational stress and alcohol use, ultimately promoting cognitive health and operational readiness in this vulnerable occupational group.

CRediT authorship contribution statement

Chaewon Suh: Writing – review & editing, Writing – original draft, Investigation, Formal analysis, Data curation. **Hyeonji Lee:** Writing – review & editing, Writing – original draft, Investigation, Formal analysis, Data curation. **Hyeonseok Jeong:** Writing – review & editing, Formal analysis. **Yoonji Joo:** Writing – review & editing, Investigation, Data curation. **Youngeun Shim:** Writing – review & editing, Investigation, Data curation. **Yejin Choi:** Writing – review & editing, Investigation, Data curation. **In Kyoon Lyoo:** Writing – review & editing, Supervision, Resources, Funding acquisition, Conceptualization. **Sujung Yoon:** Writing – review & editing, Resources, Project administration, Funding acquisition, Formal analysis, Conceptualization.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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None.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.brainresbull.2026.111950.

Data availability

The unidentified data supporting the findings of this study are available from the corresponding author upon reasonable request. The data are not publicly available due to privacy and ethical restrictions.

References

Antonenko, D., Brauer, J., Meinzer, M., Fengler, A., Kerti, L., Friederici, A.D., Flöel, A., 2013. Functional and structural syntax networks in aging. NeuroImage 83, 513–523. https://doi.org/10.1016/j.neuroimage.2013.07.018.

Bai, Y., Tan, J., Liu, X., Cui, X., Li, D., Yin, H., 2022. Resting-state functional connectivity of the sensory/somatomotor network associated with sleep quality: evidence from 202 young male samples. Brain Imaging Behav. 16, 1832–1841. https://doi.org/10.1007/s11682-022-00654-5.

Beckmann, C.F., Smith, S.M., 2004. Probabilistic independent component analysis for functional magnetic resonance imaging. IEEE Trans. Med Imaging 23, 137–152. https://doi.org/10.1109/TMI.2003.822821.

Fleming, L.L., Harnett, N.G., Ressler, K.J., 2024. Sensory alterations in post-traumatic stress disorder. Curr. Opin. Neurobiol. 84, 102821. https://doi.org/10.1016/j.conb.2023.102821.

Frost, C., Toczko, M., Merrigan, J.J., Martin, J.R., 2021. The effects of sleep on firefighter occupational performance and health: a systematic review and call for action. Sleep. Epidemiol. 1, 100014.

Griffanti, L., Salimi-Khorshidi, G., Beckmann, C.F., Auerbach, E.J., Douaud, G., Sexton, C. E., Smith, S.M., 2014. ICA-based artefact removal and accelerated fMRI acquisition for improved resting state network imaging. Neuroimage 95, 232–247. https://doi.org/10.1016/j.neuroimage.2014.03.034.

Grillon, C., Davis, M., 1997. Effects of stress and shock anticipation on prepulse inhibition of the startle reflex. Psychophysiology 34, 511–517. https://doi.org/10.1111/j.1469-8986.1997.tb01737.x.

Hancock, P.A., Ross, J.M., Szalma, J.L., 2007. A meta-analysis of performance response under thermal stressors. Hum. Factors 49, 851–877. https://doi.org/10.1518/001872007X230226.

Heaton, A., Gooding, A., Cherner, M., Umlauf, A., Franklin, D.R., Rivera Mindt, M., Marquine, M.J., 2021. Demographically-adjusted norms for the grooved pegboard and finger tapping tests in spanish-speaking adults: results from the neuropsychological norms for the U.S.-Mexico border region in spanish (NP-NUMBRS) project. Clin. Neuropsychol. 35, 396–418. https://doi.org/10.1080/13854046.2020.1713400.

Jeong, H., Park, S., Dager, S.R., Lim, S.M., Lee, S.L., Hong, H., Lyoo, I.K., 2019. Altered functional connectivity in the fear network of firefighters with repeated traumatic stress. Br. J. Psychiatry 214, 347–353. https://doi.org/10.1192/bjp.2018.260.

Karnick, A.T., Buerke, M., Caulfied, N., Trussell, D., Capron, D.W., Vujanovic, A., 2022. Alcohol use in firefighters: a network model of behaviors and transdiagnostic risk. Drug Alcohol Depend. 241, 109677. https://doi.org/10.1016/j.drugalcdep.2022.109677.

Kim, J.E., Dager, S.R., Jeong, H.S., Ma, J., Park, S., Kim, J., Lyoo, I.K., 2018. Firefighters, posttraumatic stress disorder, and barriers to treatment: results from a nationwide total population survey. PLoS One 13, e0190630. https://doi.org/10.1371/journal.pone.0190630.

Kim, M., Lee, D., Kim, W., Eun Lee, J., Lee, J., Tae Kim, Y., Jung, Y.C., 2022. Associations between altered functional connectivity of attentional networks and sleep quality among firefighters. Neurosci. Lett. 791, 136924. https://doi.org/10.1016/j.neulet.2022.136924.

Lee, D., Kim, W., Lee, J.E., Lee, J., Kim, Y.T., Lee, S.K., Jung, Y.C., 2022. Changes in intrinsic functional brain connectivity related to occupational stress of firefighters. Psychiatry Res 314, 114688. https://doi.org/10.1016/j.psychres.2022.114688.

Lefebvre, S., Gehrig, G., Nadesalingam, N., Nuoffer, M.G., Kyrou, A., Wuthrich, F., Walther, S., 2024. The pathobiology of psychomotor slowing in psychosis: altered cortical excitability and connectivity. Brain 147, 1423–1435. https://doi.org/10.1093/brain/awad395.

Linke, A.C., Kinnear, M.K., Kohli, J.S., Fong, C.H., Lincoln, A.J., Carper, R.A., Muller, R. A., 2020. Impaired motor skills and atypical functional connectivity of the sensorimotor system in 40- to 65-year-old adults with autism spectrum disorders. Neurobiol. Aging 85, 104–112. https://doi.org/10.1016/j.neurobiolaging.2019.09.018.

Maleki, N., Sawyer, K.S., Levy, S., Harris, G.J., Oscar-Berman, M., 2022. Intrinsic brain functional connectivity patterns in alcohol use disorder. Brain Commun. 4, fcac290. https://doi.org/10.1093/braincomms/fcac290.

Mann, F.D., Mueller, A.K., Zeig-Owens, R., Choi, J., Prezant, D.J., Carr, M.M., Clouston, S.A.P., 2025. Prevalence of mild and severe cognitive impairment in world trade center exposed fire department of the city of new york (FDNY) and general emergency responders. Am. J. Ind. Med 68, 160–174. https://doi.org/10.1002/ajim.23685.

Menon, V., 2023. 20 years of the default mode network: a review and synthesis. Neuron 111, 2469–2487. https://doi.org/10.1016/j.neuron.2023.04.023.

Ochi, R., Ueno, F., Sakuma, M., Tani, H., Tsugawa, S., Graff-Guerrero, A., Nakajima, S., 2022. Patterns of functional connectivity alterations induced by alcohol reflect somatostatin interneuron expression in the human cerebral cortex. Sci. Rep. 12, 7896. https://doi.org/10.1038/s41598-022-12035-5.

Pijlman, F.T., Herremans, A.H., van de Kieft, J., Kruse, C.G., van Ree, J.M., 2003. Behavioural changes after different stress paradigms: prepulse inhibition increased after physical, but not emotional stress. Eur. Neuropsychopharmacol. 13, 369–380. https://doi.org/10.1016/s0924-977x(03)00040-3.

Power, J.D., Barnes, K.A., Snyder, A.Z., Schlaggar, B.L., Petersen, S.E., 2012. Spurious but systematic correlations in functional connectivity MRI networks arise from subject motion. NeuroImage 59, 2142–2154. https://doi.org/10.1016/j.neuroimage.2011.10.018.

Reynaud, E., Guedj, E., Souville, M., Trousselard, M., Zendjidjian, X., El Khoury-Malhame, M., Khalfa, S., 2013. Relationship between emotional experience and resilience: an fMRI study in fire-fighters. Neuropsychologia 51, 845–849. https://doi.org/10.1016/j.neuropsychologia.2013.01.007.

Reynaud, E., Guedj, E., Trousselard, M., El Khoury-Malhame, M., Zendjidjian, X., Fakra, E., Khalfa, S., 2015. Acute stress disorder modifies cerebral activity of amygdala and prefrontal cortex. Cogn. Neurosci. 6, 39–43. https://doi.org/10.1080/17588928.2014.996212.

Salimi-Khorshidi, G., Douaud, G., Beckmann, C.F., Glasser, M.F., Griffanti, L., Smith, S. M., 2014. Automatic denoising of functional MRI data: combining independent component analysis and hierarchical fusion of classifiers. Neuroimage 90, 449–468. https://doi.org/10.1016/j.neuroimage.2013.11.046.

Saunders, J.B., Aasland, O.G., Babor, T.F., de la Fuente, J.R., Grant, M., 1993. Development of the alcohol use disorders identification test (AUDIT): WHO Collaborative project on early detection of persons with harmful alcohol consumption–II. Addiction 88, 791–804. https://doi.org/10.1111/j.1360-0443.1993.tb02093.x.

Shaw, S.B., Terpou, B.A., Densmore, M., Théberge, J., Frewen, P., McKinnon, M.C., Lanius, R.A., 2023. Large-scale functional hyperconnectivity patterns in trauma-related dissociation: an rs-fMRI study of PTSD and its dissociative subtype. Nat. Ment. Health 1, 711–721.

Smith, S.M., Nichols, T.E., 2009. Threshold-free cluster enhancement: addressing problems of smoothing, threshold dependence and localisation in cluster inference. Neuroimage 44, 83–98. https://doi.org/10.1016/j.neuroimage.2008.03.061.

Soares, J.M., Sampaio, A., Ferreira, L.M., Santos, N.C., Marques, P., Marques, F., Sousa, N., 2013a. Stress impact on resting state brain networks. PLoS One 8, e66500. https://doi.org/10.1371/journal.pone.0066500.

Soares, J.M., Sampaio, A., Marques, P., Ferreira, L.M., Santos, N.C., Marques, F., Sousa, N., 2013b. Plasticity of resting state brain networks in recovery from stress. Front Hum. Neurosci. 7, 919. https://doi.org/10.3389/fnhum.2013.00919.

Solesio-Jofre, E., Beets, I.A.M., Woolley, D.G., Pauwels, L., Chalavi, S., Mantini, D., Swinnen, S.P., 2018. Age-dependent modulations of resting state connectivity following motor practice. Front Aging Neurosci. 10, 25. https://doi.org/10.3389/fnagi.2018.00025.

Solesio-Jofre, E., Serbruyns, L., Woolley, D.G., Mantini, D., Beets, I.A., Swinnen, S.P., 2014. Aging effects on the resting state motor network and interlimb coordination. Hum. Brain Mapp. 35, 3945–3961. https://doi.org/10.1002/hbm.22450.

Strik, M., Chard, D.T., Dekker, I., Meijer, K.A., Eijlers, A.J., Pardini, M., Schoonheim, M. M., 2021. Increased functional sensorimotor network efficiency relates to disability in multiple sclerosis. Mult. Scler. 27, 1364–1373. https://doi.org/10.1177/1352458520966292.

Tsur, N., Defrin, R., Lahav, Y., Solomon, Z., 2018. The traumatized body: long-term PTSD and its implications for the orientation towards bodily signals. Psychiatry Res. 261, 281–289. https://doi.org/10.1016/j.psychres.2017.12.083.

Wagner, S.L., White, N., Buys, N., Carey, M.G., Corneil, W., Fyfe, T., Fleischmann, M.H., 2021. Systematic review of mental health symptoms in firefighters exposed to routine duty-related critical incidents. Traumatology 27, 285–302. https://doi.org/10.1037/trm0000275.

Wolffe, T.A.M., Robinson, A., Clinton, A., Turrell, L., Stec, A.A., 2023. Mental health of UK firefighters. Sci. Rep. 13, 62. https://doi.org/10.1038/s41598-022-24834-x.

Yan, Z., Zhao, M., Qi, Y., Chen, A., Mou, H., Jia, X., Wang, Y., 2025. A systematic review and coordinate-based meta-analysis of resting-state fMRI in athletes from open and closed skills sports. Sci. Rep. 15, 21870. https://doi.org/10.1038/s41598-025-07192-2.

Zhang, Y., Dai, Z., Hu, J., Qin, S., Yu, R., Sun, Y., 2020. Stress-induced changes in modular organizations of human brain functional networks. Neurobiol. Stress 13, 100231. https://doi.org/10.1016/j.ynstr.2020.100231.