

Neural Correlates of Attention Lapses During Continuous Tasks

Mohamed H. Zaky, *Student Member, IEEE*, Reza Shoorangiz, *Member, IEEE*, Govinda R. Poudel, *Member, IEEE*, Le Yang, *Member, IEEE*, and Richard D. Jones, *Fellow, IEEE*

Abstract— Attention lapses (ALs) are common phenomenon, which can affect our performance and productivity by slowing or suspending responsiveness. Occurrence of ALs during continuous monitoring tasks, such as driving or operating machinery, can lead to injuries and fatalities. However, we have limited understanding of what happens in the brain when ALs intrude during such continuous tasks. Here, we analyzed fMRI data from a study, in which participants performed a continuous visuomotor tracking task during fMRI scanning. A total of 68 ALs were identified from 20 individuals, using visual rating of tracking performance and video-based eye-closure. ALs were found to be associated with increased BOLD fMRI activity partially in the executive control network, and sensorimotor network. Surprisingly, we found no evidence of deactivations.

I. INTRODUCTION

An attention lapse (AL) during an active task that requires extended sustained-concentration, such as driving, can lead to a catastrophic event [1]. We often perform at a high level at the start of a task but are much less likely to maintain this level of performance over an extended period [2-5]. This degraded performance is due to our ability to respond adequately becoming increasingly impaired [6, 7]. Complete lapses of responsiveness can occur due to behavioral microsleeps (BMs) [3-8] or ALs, including mind-blanks [9] and mind-wandering [10].

ALs are largely attributed to loss of attention or diversion of attention to something else [11]. This might be an exogenous distraction, such as looking out a car's side window or changing something on the stereo [12], or something internal where our attention has been 'imprisoned in our thoughts chamber' [13]. Internal (endogenous) distraction can be mind-wandering or mind-blanking. In mind-wandering, attention shifts from the task at hand to self-generated thoughts [14], and can be (i) voluntary in which the subject chooses to divide his/her attention between task-related and task-unrelated thoughts [15] and usually does not completely decouple attention from the external world, or (ii) involuntary, which may be a personal trait [16] and often results in complete decoupling from the external world. Mind-blanking, in which the mind 'goes away', is a lapse in which there is a complete loss of attentional focus but without loss of

consciousness. Mind-blanking has been considered to be an extreme case of decoupling of perception and attention [9].

The task's nature (boring, exhausting, etc.) [17, 18], time-on-task [8, 18], and environment factors [11] are important factors which should also be considered while studying any type of lapse. Also, propensity for ALs varies between subjects, dependent on cognitive abilities and other individual differences [19, 20]. Explanations for ALs include (1) task monotony leading to increased distraction due to self-generated thoughts (i.e., mind-wandering), and (2) task demands that lead to depletion of the resources needed to carry out the information processing required to perform the task [21, 22].

Previous studies have detected ALs based on subjective reports, such as probe-caught [23], self-reports [24], and monitoring behavioural responsiveness (e.g., reaction time) during discrete tasks [25]. Despite extensive use of the thought probe-caught technique, there is a lack of consistency in the methodological approach [26]. Discrete vigilance tasks, which have also been used extensively, lack temporal accuracy/resolution to identify the onset and offset of intermittent ALs. More recent studies have attempted to use continuous tasks, such as driving and visuomotor tracking tasks, which can provide sufficient temporal resolution required to sample ALs [4, 5, 8, 27, 28]. However, these studies have largely focused on microsleeps. In contrast, we identify ALs during a baseline of good responsiveness in a continuous visuomotor tracking task and analyse functional magnetic resonance imaging (fMRI) data during ALs to reveal their neural correlates.

II. METHODOLOGY

A. Data

This study re-examines fMRI data from a previously published study, in which participants performed a 50-min visuomotor tracking task inside an MRI scanner [3]. Briefly, twenty healthy subjects (10M, 10F, 21—45 years) with no history of neurological, psychiatric, or sleep disorder participated in the study. The subjects performed a continuous 2D visuomotor tracking task using a finger joystick. Eye video (Visible Eye), 64-ch. EEG (MagLink), and whole-head fMRI

* This work was supported by the University of Canterbury and the New Zealand Brain Research Institute.

Mohamed Zaky is with the Department of Electrical and Computer Engineering at the University of Canterbury, the Arab Academy for Science, Technology and Maritime Transport in Egypt, and the Christchurch Neurotechnology Research Programme, and the New Zealand Brain Research Institute, Christchurch, New Zealand (mohamed.zaky@nzbrri.org).

Reza Shoorangiz is with the Department of Electrical and Computer Engineering at the University of Canterbury, the Christchurch Neurotechnology Research Programme, and the New Zealand Brain Research Institute, Christchurch, New Zealand (reza.shoorangiz@nzbrri.org).

Govinda Poudel is with the Christchurch Neurotechnology Research Programme, and the Australian Catholic University (govinda.poudel@acu.edu.au).

Le Yang is with the Department of Electrical and Computer Engineering at the University of Canterbury (le.yang@canterbury.ac.nz).

Richard Jones is with the Department of Electrical and Computer Engineering at the University of Canterbury, the Christchurch Neurotechnology Research Programme, and the New Zealand Brain Research Institute, Christchurch, New Zealand (richard.jones@nzbrri.org).

(GE 3T, repetition time (TR) = 2.5 s) were acquired. SyncPlayer™ software was used to visualize and rate the tracking response and eye-video data.

B. Events' Rating

Events characterized by disjointed/flat tracking for more than 500 ms and no phasic eye closure except for normal blinking were labelled as ALs, while BMs were characterized by (1) flat/incoherent tracking > 500 ms [nearly all flat during at least part of the event], (2) full or partial phasic eye closure (excluding blinks), and (3) clear behavioural indications of drowsiness/sleepiness. If the duration of a BM exceeded 15 s, it was considered a sleep episode.

Another event we have observed is what we have termed a *drowsiness-related impaired-responsiveness event* (DIRE). It is a distinct drowsiness-related transient reduction in performance but without complete loss of performance. A DIRE is characterized by (1) an epoch of very poor, but not incoherent, tracking relative to baseline tracking for > 500 ms, and (2) full or partial phasic eye closure (excluding blinks).

Finally, any other clear transient episode of poor tracking was labelled a voluntary reduced-responsiveness event (VRRE), which could be fatigue-related (e.g., voluntary eye closure [excluding blinks], rubbing eyes, squeezing eyes shut) or non-fatigue-related (e.g., sneezing, cramp in hand). It is usually an episode of flat/incoherent tracking > 500 ms but can be partially compensated for via predictive motor planning.

C. Preprocessing and Denoising

Using FEAT, part of FSL (FMRIB's Software Library; www.fmrib.ox.ac.uk/fsl), the blood-oxygen-level-dependent (BOLD) 4D images were motion corrected using MCFLIRT [29], high-pass filtered at 100 s [30], spatially smoothed with a Gaussian kernel (full width at half maximum) at 5 mm [30], and slice-time corrected for interleaved slices. BET was used for brain extraction [31]. Within FEAT, MELODIC ICA [32] was applied to decompose the 4D fMRI images into independent components (ICs), followed by visual inspection [33] and the ICA-AROMA algorithm [34] to identify and discard motion-related and physiological noise components.

D. Registration

Linear registration by FLIRT [29] with 6 degrees of freedom (DOF) was carried out to register functional images to structural images, and 12 DOF was used to register structural images to standard MNI space.

E. Subject-Level Analysis

To perform the subject-level analysis through FEAT [35], a general linear model (GLM) was built by accounting for task-related regressors: ALs, BMs, Sleep, DIREs, and VRREs. Two covariates were also included: (1) tracking-target-related variability, represented by the average target speed during each TR scaled to a unit height, and (2) poor responsive tracking, defined from a threshold based on tracking error in the first 2 min of the session. All regressors and covariates were then convolved with a double-gamma hemodynamic response function (HRF). Contrast was defined to test ALs versus baseline of good tracking by accounting for poor responsive tracking in the GLM using a binary regressor with a value of '1' during poor tracking, in addition to the other events of interest and tracking-target-related variability. The

temporal derivatives of all events of interest and covariates were included.

Due to an fMRI scanning restriction, the task had to be divided into two contiguous runs. Consequently, we averaged the two runs for each subject, to have only one contrast of parameter estimate (COPE) image per subject, representing ALs versus good tracking.

F. Group-Level Analysis

Of the 20 subjects in the study, 16 had 1–14 ALs, with an overall total of 68 ALs. To ensure stability, only subjects with 2 or more ALs in at least one run were included in the group-level analysis, resulting in a total of 11 subjects and 60 ALs.

As we were only interested in changes in activity in the brain's grey matter, we used FAST [36] to segment the grey matter out of each COPE image at the subject level. Group-level analysis was done using a one-sample t-test over all the subjects who had ALs, using Randomise for statistical analysis [37]. The results were then corrected for multiple comparisons using threshold-free cluster enhancement (TFCE) [38] at $p < 0.05$. Only clusters with a voxel size larger than 50 voxels were considered.

III. RESULTS

The ALs from the 16 subjects had an average duration of 2.11 s, which is less than the TR (2.5 s). The durations ranged 0.57–8.13 s, with 49 of these being below the TR.

Group-level analysis revealed a neural activation in one cluster as shown in Fig. 1 and Table I.

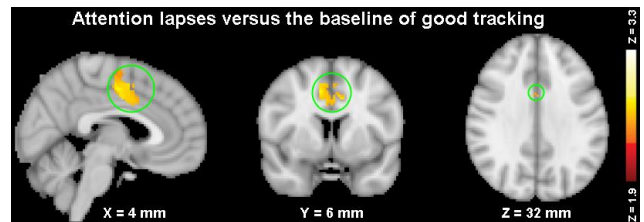


Fig. 1. Group-level significance result of increased BOLD activity for ALs versus the baseline of good responsive tracking. The cluster is labeled with its peak value in MNI coordinates. The activity in the cluster is circled in green for axial, sagittal, and coronal slices (in radiological convention).

TABLE I. SIGNIFICANT CLUSTERS OF INCREASED BOLD ACTIVITY

Cluster	Voxels	Z-MAX	Z-MAX X (mm)	Z-MAX Y (mm)	Z-MAX Z (mm)
1	393	3.3	4	6	32

The Atlasquery toolbox was used to report brain regions related to the cluster following Randomise. The Harvard-Oxford cortical atlas was the reference, and only major regions that contributed to more than 50% of the cluster are reported in Table II.

TABLE II. REGIONS FORMING CLUSTERS OF INCREASED BOLD ACTIVITY

Cluster	Regions	Side
1	Juxtapositional Lobule Cortex (formerly Supplementary Motor Cortex)	R,L
	Cingulate Gyrus, anterior division	R,L

The cluster is in regions partially overlapping two brain networks based on [39]: executive control network (ECN) and sensorimotor network (SMN).

IV. DISCUSSION

The neural signature of ALs during a continuous task has been investigated. Our results revealed activation in 1 cluster (see Table 1 and Fig. 1), falling partially within 2 brain networks: ECN and SMN. Our findings conflict with previous studies on mind-wandering [40], which showed activation in the default mode network (DMN), and mind-blanking [41], for which the neural signature also includes the DMN, as well as both activation and deactivation in other areas. In fMRI studies in which ALs were defined by slow reaction times, the DMN has also been shown to be active. This includes the psychomotor vigilance task (PVT) [42], the gradual onset continuous performance task (gradCPT) [43, 44], and a selective attention task [25, 45].

The key difference between our study and the previous literature on ALs is that we were able to accurately determine their duration. We found that $\sim 72\%$ of ALs have durations less than the TR of the fMRI scanner. Analysis revealed activations in two specific regions: supplementary motor cortex and anterior cingulate gyrus, related to the SMN and ECN respectively. Because of the relatively short average duration of the ALs, the BOLD signal might not be able to detect the neural signature of the AL. According to previous studies, the SMN and ECN are not involved in activations or deactivations relating to ALs.

However, seeing activation in these two regions was not by chance: activation in the supplementary motor cortex is associated with finger movement [46, 47], which is the case in our task in which the subjects used their fingers for tracking. Activation in the anterior cingulate gyrus is also associated with brief ALs [25], as we found, as the anterior cingulate gyrus is involved in the resumption of our attention [48-51]. In essence, because of the temporal limitation in the BOLD signal, our results may be more related to the recovery process of an AL rather than being indicative of the AL itself.

V. CONCLUSION

Our study aimed to reveal the neural signature of ALs during a continuous task in which there was no interruption of the AL phenomenon, as opposed to the probe-caught technique or any other subjective report. Conversely, without subjective reports, we have no independent (even if subjective) behavioural estimate of whether the ALs were due to mind-wandering or mind-blanks. In addition, we were able to estimate the average duration of ALs (2.11 s), which, being shorter than the TR, indicates that fMRI alone is unlikely to be able to reveal all aspects of the neural signature of ALs.

There were several limitations in this study: (1) having only 11 subjects with a total of 60 events is not enough to reveal more subtle aspects of the neural signature of ALs, (2) given the delay in the BOLD signal, represented by the HRF function, and the short duration of ALs, we may not have been able to reveal any deactivations. Thus, we will use simultaneously recorded EEG to gain a much higher temporal resolution (albeit with a much lower spatial resolution) of

both neural activations and deactivations. We will also explore functional connectivity analysis to see changes in connectivity within and between the brain networks related to ALs.

REFERENCES

- [1] J. A. Cheyne, J. S. A. Carriere, and D. Smilek, "Absent-mindedness: Lapses of conscious awareness and everyday cognitive failures," *Conscious. Cogn.*, vol. 15, no. 3, pp. 578-592, 2006.
- [2] R. A. McKinley, L. K. McIntire, R. Schmidt, D. W. Repperger, and J. A. Caldwell, "Eye metrics: An alternative vigilance detector for military operators," *Hum. Factors*, vol. 53, no. 4, pp. 403-414, 2011.
- [3] G. R. Poudel, C. R. H. Innes, P. J. Bones, R. Watts, and R. D. Jones, "Losing the struggle to stay awake: Divergent thalamic and cortical activity during microsleeps," *Hum. Brain Mapp.*, vol. 35, no. 1, pp. 257-269, 2014.
- [4] J. Toppi, L. Astolfi, G. R. Poudel, C. R. H. Innes, F. Babiloni, and R. D. Jones, "Time-varying effective connectivity of the cortical neuroelectric activity associated with behavioural microsleeps," *NeuroImage*, vol. 124, pp. 421-432, 2016.
- [5] G. R. Poudel, C. R. H. Innes, and R. D. Jones, "Temporal evolution of neural activity and connectivity during microsleeps when rested and following sleep restriction," *NeuroImage*, vol. 174, pp. 263-273, 2018.
- [6] M. T. R. Peiris, R. D. Jones, P. R. Davidson, G. J. Carroll, and P. J. Bones, "Frequent lapses of responsiveness during an extended visuomotor tracking task in non-sleep-deprived subjects," *J. Sleep Res.*, vol. 15, no. 3, pp. 291-300, 2006.
- [7] G. R. Poudel, C. R. H. Innes, P. J. Bones, and R. D. Jones, "The relationship between behavioural microsleeps, visuomotor performance and EEG theta," *Proc. Ann. Int. Conf. IEEE Eng. Med. Biol. Soc.*, pp. 4452-4455, 2010.
- [8] G. R. Poudel, C. R. H. Innes, and R. D. Jones, "Distinct neural correlates of time-on-task and transient errors during a visuomotor tracking task after sleep restriction," *NeuroImage*, vol. 77, pp. 105-113, 2013.
- [9] A. F. Ward and D. M. Wegner, "Mind-blanking: When the mind goes away," *Front. Psychol.*, vol. 4, p. 650, 2013.
- [10] T. R. M. Peiris, R. D. Paul, J. B. Philip, and D. J. Richard, "Detection of lapses in responsiveness from the EEG," *J. Neural Eng.*, vol. 8, no. 1, p. 016003(15pp), 2011.
- [11] N. Unsworth and B. D. McMillan, "Similarities and differences between mind-wandering and external distraction: A latent variable analysis of lapses of attention and their relation to cognitive abilities," *Acta Psychol.*, vol. 150, pp. 14-25, 2014.
- [12] C. Anderson, A. W. J. Wales, and J. A. Horne, "PVT lapses differ according to eyes open, closed, or looking away," *Sleep*, vol. 33, no. 2, pp. 197-204, 2010.
- [13] S. K. D'Mello, "Giving eyesight to the blind: Towards attention-aware AIED," *Int. J. Artif. Intell. Educ.*, vol. 26, no. 2, pp. 645-659, 2016.
- [14] S. Huijser, M. K. van Vugt, and N. A. Taatgen, "The wandering self: Tracking distracting self-generated thought in a cognitively demanding context," *Conscious. Cogn.*, vol. 58, pp. 170-185, 2018.
- [15] C. Ottaviani, L. Shahabi, M. Tarvainen, I. Cook, M. Abrams, and D. Shapiro, "Cognitive, behavioral, and autonomic correlates of mind wandering and perseverative cognition in major depression," *Front. Neurosci.*, vol. 8, no. 433, pp. 1-9, 2015.
- [16] C. Gil-Jardiné *et al.*, "The distracted mind on the wheel: Overall propensity to mind wandering is associated with road crash responsibility," *PLoS One*, vol. 12, no. 8, p. e0181327, 2017.
- [17] G. S. Larue, A. Rakotonirainy, and A. N. Pettitt, "Predicting reduced driver alertness on monotonous highways," *IEEE Pervasive Comput.*, vol. 14, no. 2, pp. 78-85, 2015.
- [18] R. J. Buckley, W. S. Helton, C. R. H. Innes, J. C. Dalrymple-Alford, and R. D. Jones, "Attention lapses and behavioural microsleeps during tracking, psychomotor vigilance, and dual tasks," *Conscious. Cogn.*, vol. 45, pp. 174-183, 2016.
- [19] N. Unsworth, T. S. Redick, C. E. Lakey, and D. L. Young, "Lapses in sustained attention and their relation to executive control and fluid abilities: An individual differences investigation," *Intelligence*, vol. 38, no. 1, pp. 111-122, 2010.
- [20] B. R. D. Burdett, S. G. Charlton, and N. J. Starkey, "Not all minds wander equally: The influence of traits, states and road environment

- factors on self-reported mind wandering during everyday driving," *Accid. Anal. Prev.*, vol. 95, pp. 1-7, 2016.
- [21] W. S. Helton and P. N. Russell, "Feature absence–presence and two theories of lapses of sustained attention," *Psychol. Res.*, vol. 75, no. 5, pp. 384-392, 2011.
- [22] D. R. Thomson, D. Besner, and D. Smilek, "A resource-control account of sustained attention: Evidence from mind-wandering and vigilance paradigms," *Perspect. Psychol. Sci.*, vol. 10, no. 1, pp. 82-96, 2015.
- [23] C. Van den Driessche *et al.*, "Attentional lapses in Attention-Deficit/Hyperactivity Disorder: Blank rather than wandering thoughts," *Psychol. Sci.*, vol. 28, no. 10, pp. 1375-1386, 2017.
- [24] A. Efklides and A. Touroutoglou, "Prospective memory failure and the metacognitive experience of "Blank in the Mind"," in *Trends and Prospects in Metacognition Research*, A. Efklides and P. Misailidis Eds. Boston, MA: Springer US, 2010, pp. 105-126.
- [25] D. H. Weissman, K. C. Roberts, K. M. Visscher, and M. G. Woldorff, "The neural bases of momentary lapses in attention," *Nat. Neurosci.*, vol. 9, pp. 971-978, 2006.
- [26] Y. Weinstein, H. J. De Lima, and T. van der Zee, "Are you mind-wandering, or is your mind on task? The effect of probe framing on mind-wandering reports," *Psych. Bull. Rev.*, vol. 25, no. 2, pp. 754-760, 2017.
- [27] Y. Jonmohamadi, G. R. Poudel, C. R. H. Innes, and R. D. Jones, "Microsleeps are associated with stage-2 sleep spindles from hippocampal-temporal network," *Int. J. Neural. Syst.*, vol. 26, no. 04, p. 1650015(12pp), 2016.
- [28] J. Toppi *et al.*, "Time-varying functional connectivity for understanding the neural basis of behavioral microsleeps," *Proc. Ann. Int. Conf. IEEE Eng. Med. Biol. Soc.*, pp. 4708-4711, 2012.
- [29] M. Jenkinson, P. Bannister, M. Brady, and S. Smith, "Improved optimization for the robust and accurate linear registration and motion correction of brain images," *NeuroImage*, vol. 17, no. 2, pp. 825-841, 2002.
- [30] M. Jenkinson and S. M. Smith, "Pre-processing of BOLD fMRI data," ed: Oxford University Centre for Functional MRI of the Brain (FMRIB), 2006, p. 1.
- [31] M. Jenkinson, M. Pechaud, and S. Smith, "BET2: MR-based estimation of brain, skull and scalp surfaces," in "Proc. 11th Ann. Meet. Org. Hum. Brain Map.," 2005.
- [32] S. M. Smith *et al.*, "Advances in functional and structural MR image analysis and implementation as FSL," *NeuroImage*, vol. 23, pp. S208-S219, 2004.
- [33] L. Griffanti *et al.*, "Hand classification of fMRI ICA noise components," *NeuroImage*, vol. 154, pp. 188-205, 2017.
- [34] R. H. R. Pruim, M. Mennes, D. van Rooij, A. Llera, J. K. Buitelaar, and C. F. Beckmann, "ICA-AROMA: A robust ICA-based strategy for removing motion artifacts from fMRI data," *NeuroImage*, vol. 112, pp. 267-277, 2015.
- [35] M. W. Woolrich, B. D. Ripley, M. Brady, and S. M. Smith, "Temporal autocorrelation in univariate linear modeling of FMRI data," *NeuroImage*, vol. 14, no. 6, pp. 1370-1386, 2001.
- [36] Y. Zhang, M. Brady, and S. Smith, "Segmentation of brain MR images through a hidden Markov random field model and the expectation-maximization algorithm," *IEEE Trans. Med. Imaging*, vol. 20, no. 1, pp. 45-57, 2001.
- [37] A. M. Winkler, G. R. Ridgway, M. A. Webster, S. M. Smith, and T. E. Nichols, "Permutation inference for the general linear model," *NeuroImage*, vol. 92, pp. 381-397, 2014.
- [38] S. M. Smith and T. E. Nichols, "Threshold-free cluster enhancement: Addressing problems of smoothing, threshold dependence and localisation in cluster inference," *NeuroImage*, vol. 44, no. 1, pp. 83-98, 2009.
- [39] S. M. Smith *et al.*, "Correspondence of the brain's functional architecture during activation and rest," *Proc. Natl. Acad. Sci. U. S. A.*, vol. 106, no. 31, p. 13040, 2009.
- [40] J. R. Andrews-Hanna, "The brain's default network and its adaptive role in internal mentation," *Neuroscientist*, vol. 18, no. 3, pp. 251-270, 2012.
- [41] T. Kawagoe, K. Onoda, and S. Yamaguchi, "The neural correlates of "mind blanking": When the mind goes away," *Hum. Brain Mapp.*, vol. 0, no. 0, 2019.
- [42] S. P. Drummond, A. Bischoff-Grethe, D. F. Dinges, L. Ayalon, S. C. Mednick, and M. Meloy, "The neural basis of the psychomotor vigilance task," *Sleep*, vol. 28, no. 9, pp. 1059-1068, 2005.
- [43] M. Esterman, S. K. Noonan, M. Rosenberg, and J. DeGutis, "In the zone or zoning out? Tracking behavioral and neural fluctuations during sustained attention," *Cereb. Cortex.*, vol. 23, no. 11, pp. 2712-2723, 2013.
- [44] F. C. Fortenbaugh, D. Rothlein, R. McGlinchey, J. DeGutis, and M. Esterman, "Tracking behavioral and neural fluctuations during sustained attention: A robust replication and extension," *NeuroImage*, vol. 171, pp. 148-164, 2018.
- [45] M. W. L. Chee *et al.*, "Lapsing during sleep deprivation Is associated with distributed changes in brain activation," *J. Neurosci.*, vol. 28, no. 21, p. 5519, 2008.
- [46] D. Wildgruber, M. Erb, U. Klose, and W. Grodd, "Sequential activation of supplementary motor area and primary motor cortex during self-paced finger movement in human evaluated by functional MRI," *Neurosci. Lett.*, vol. 227, no. 3, pp. 161-164, 1997.
- [47] H. Shibasaki *et al.*, "Both primary motor cortex and supplementary motor area play an important role in complex finger movement," *Brain*, vol. 116, no. 6, pp. 1387-1398, 1993.
- [48] D. H. Weissman, A. Gopalakrishnan, C. Hazlett, and M. Woldorff, "Dorsal anterior cingulate cortex resolves conflict from distracting stimuli by boosting attention toward relevant events," *Cereb. Cortex.*, vol. 15, no. 2, pp. 229-237, 2005.
- [49] M. T. Banich *et al.*, "fMRI studies of Stroop tasks reveal unique roles of anterior and posterior brain systems in attentional selection," *J. Cogn. Neurosci.*, vol. 12, no. 6, pp. 988-1000, 2000.
- [50] A. W. MacDonald, J. D. Cohen, V. A. Stenger, and C. S. Carter, "Dissociating the role of the dorsolateral prefrontal and anterior cingulate cortex in cognitive control," *Science*, vol. 288, no. 5472, pp. 1835-1838, 2000.
- [51] T. Paus, "Primate anterior cingulate cortex: where motor control, drive and cognition interface," *Nature reviews neuroscience*, vol. 2, no. 6, pp. 417-424, 2001.