EEG microstates at rest predict task performance

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Introduction. High-level cognitive functions are usually required when dealing with novel and complex tasks. They allow the human being to adapt, that is to say, to be flexible in front of the changing environmental demand. Especially, executive functions (EFs) encompass a complex set of cognitive functions that include: updating, inhibition and shifting (Miyake et al., 2000; Friedman et al., 2017). The main purpose of this preliminary work was to find neurophysiological markers of executive functioning at rest in order to predict future task performance. To do so, we measured the brain activity of 9 participants with an EEG device, and performed EEG microstates analyses to evaluate possible correlates of performance on a complex task: Space Fortress (SF).

SF is a video game that has been developed as a complex laboratory task to study skill acquisition and to train participants to improve cognition (Mané & Donhin, 1989). Although this task has been extensively used in cognitive training studies, few studies have investigated its cognitive correlates (Boot et al., 2008). Therefore, our first aim was to test SF external validity, that is, to assess to what extent SF performance is associated to classical executive functions tasks. Our second aim was to explore the relationship between resting-state EEG microstates metrics and SF performance. Four proto-typical microstates have been repeatedly described in the literature (A, B, C and D). These are defined as semi-stable electric potential configurations on the scalp that last approximately 60-120 ms (Michel & Koenig, 2018). These microstates are supposedly related to the activity of distinct functional networks such as the Default Mode Network or the Executive Control Network (Britz et al., 2010; Van de Ville et al., 2010). Especially, the microstates C and D have been associated with high-level cognitive functions such as fluid intelligence and working memory (Santarnecchi et al., 2017, Seitzman et al., 2017). Therefore, we expected the microstates metrics to be related to executive functions. Our main hypothesis was that the spatio-temporal dynamics (*i.e.,* number of occurrences and mean duration of microstates C and D) predict SF performance.

Figure 1. The Space Fortress video game. The participants must control a ship in the space and destroy a fortress and moving mine while capturing bonuses.

Methods and results. 9 participants performed a 5-min resting-state during which their cerebral activity was measured with a 64-channel EEG device (Active-two Biosemi). Following the EEG acquisition, they played the SF video game (see Figure 1) and performed nine executive function tasks (anti-saccade, stop-signal, Stroop, keep-track, letter-memory, dual n-back, color-shape and category-switch) following the same procedure than Miyake & Friedman (2000).

The pre-processing of EEG data was performed using a standardized pre-processing with AUTOMAGIC software (Pedroni et al., 2018). Then, EEG microstates were extracted following recommendations from the literature (Michel & Koenig, 2018; see figure 2), albeit with an additional clustering step (*i.e.,* first & second level clustering). The number of occurrences and mean duration of each of the four proto-typical microstates were finally extracted.

SF performance was evaluated following the same procedure as Chenot et al. (2021). SF external validity has been assessed by performing a correlation analysis between the average z-score of all individual executive function tasks scores and the z-score of the SF score. We observed a strong and positive relationship (r = .898, p < .001), suggesting that SF performance largely relies on executive functions.

To test our main hypothesis (i.e., SF performance can be predicted by spatio-temporal brain activity at rest) we performed correlations analyses between resting-state microstates C and D metrics and SF z-score (see results in table 1). We found a significant correlation with the microstate C mean duration, and non-significant correlations (but high coefficient) with microstates D mean duration and number of occurrences.

Conclusion. Our preliminary results show for the first time that SF performance has the potential to be an excellent measure of executive functioning because it shows high external validity (r coefficient of .898 with other executive functions tests). This preliminary study shows, furthermore, that performance on a complex task can be predicted by neurophysiological markers at rest, assessed by EEG microstates analyses. We find especially interesting that mean durations of microstates C and D are positively associated with SF performance (r = .677; p < .05 and r = .624; p = .07; respectively). In other words, whenever the executive control network is predominant at rest, the longer its duration the higher the executive functioning (Santarnecchi et al., 2017, Seitzman et al., 2017). A future study to improve the statistical power (*i.e.,* 140 participants) is planned and has already been pre-registered in an open-science network (https://osf.io/fm58p/).

Better knowledge on the neurophysiological and cognitive correlates of SF could help first, to design better training protocols and second, to better understand the potential of transfer effects to other tasks. Furthermore, finding neurophysiological markers of complex task performance has several valuable applications in the neuroergonomics field. Along with other physiological, behavioral, and sociocultural markers (such as expertise and knowledge), they could potentially be used as a predictive tool to elaborate individualized trainings with focused cognitive functions.

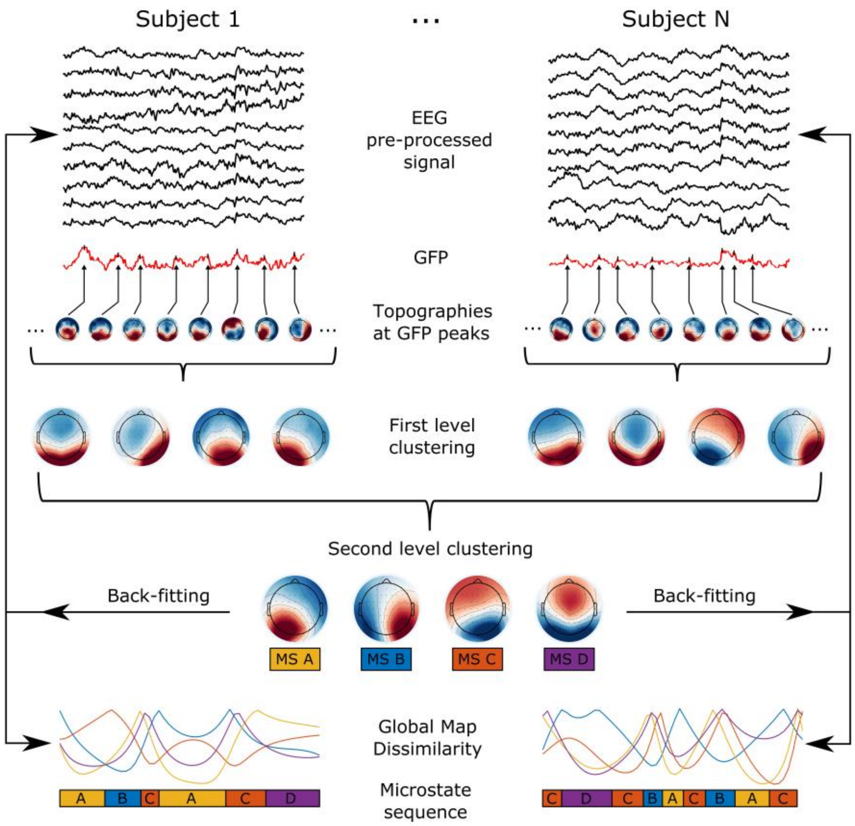

Figure 2. Pipeline of the microstate analysis. The first and second level clustering were performed using k-mean algorithms. GFP: Global Field Power (standard deviation)

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OVERVIEW OF REVIEWS

Review 1
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Contribution of the Submission

Tested external validity of Space Fortress by correlating performance on the task to performance on nine other executive function tasks. Additionally, explored relationship between resting-state EEG microstates to task performance.

Evaluation of the Contribution

Quality of Content   (10%): 6
Significance   (10%): 8
Originality   (10%): 6
Thematic Relevance   (10%): 8
Presentation   (10%): 8
Overall Recommendation (50%): 8
Total points (out of 100)   : 76

Comments for the Authors

Very nice approach, clearly written. A couple of comments/questions are offered to the authors:
-How was performance on SF assessed? How is the relevant to other applications/tasks? Similarly how was performance assessed on the other nine executive function tasks?
-How much time between the resting-state data collection and SF game play? Was the order of the tasks randomized?

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Review 2
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Contribution of the Submission

The abstract presents preliminary results validating that performance in a space fortress game used for cognitive training before is related to executive functions (measured by other cognitive tasks). Furthermore the authors were capable to show that the duration of microstates (C and D) during resting states correlates positively with the performance in playing the game afterwards.

Evaluation of the Contribution

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Quality of Content     (10%): 6
Significance           (10%): 6
Originality            (10%): 6
Thematic Relevance     (10%): 8
Presentation           (10%): 8
Overall Recommendation (50%): 7
Total points (out of 100)   : 69
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Comments for the Authors

The abstract is well written and describes important analysis steps or refers to the literature used as guidance.
A short description of the known microstates in the introduction would have helped to familiarize the reader instead of just stating A,B,C,D. Especially for the two which turn to be central for the study.
Using correlations only to ground the term 'prediction' stated in the heading is too bold for my taste. Scientifically correct would be to call correlations correlations.
There were in total 3 figures or tables included in the abstract whereas only two were allowed.
I appreciate that the work is called and treated as preliminary and that it is planned to extend the sample.

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Review 3
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Contribution of the Submission

The submission describes the idea, and the results of a pilot study, on using EEG microstates to predict subsequent performance in a computer game (representative of executive cognitive functioning)

Evaluation of the Contribution

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Quality of Content     (10%): 4
Significance           (10%): 8
Originality            (10%): 8
Thematic Relevance     (10%): 10
Presentation           (10%): 8
Overall Recommendation (50%): 6
Total points (out of 100)   : 68
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Comments for the Authors

The idea of the work, predicting upcoming cognitive performance on the basis of passively acquired signals, is very valuable and fitting to Neuroergonomics. The manuscript is clearly written. The downside is the very small number of subjects (9), where analyses are regressions on 9 points, relating performance and microstates across subjects. Therefore, I doubt the meaningfulness of the results so far, but the authors present their work as preliminary and a start of a study with 100 participants.
I wonder why a between-subject design was chosen; a within-subject design would seem to make more sense (also for practical applications).