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Prefrontal cortex activations in young adults during updating of working memory: effects of the control task and the complexity levels.



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INTRODUCTION

Recent work using the near-infrared spectroscopy (NIRS) technique to characterize the evolution of the brain metabolic activity as a function of mental load has generally compared activations between experimental and control conditions [1, 2]. However there are few works which have investigated the consistency of the control condition. The aims of this study were (a) to examine the consistency of the control condition using a test-retest procedure and (b) to more closely examine the hemodynamic variations as a function of task complexity and their relationships with subjective and behavioral data.

METHODS

Procedure : Nineteen young adults [18-22 years] performed a working memory task (n-back) with three levels of complexity (1, 2, 3-back) and a control task before (0-back1) and after (0-back2) these three levels of complexity. During each condition lasting 150 seconds, an eight-channel continuous-wave fNIRS device (Oxymon MkIII-Artinis) continuously measured concentrations changes of [HbO₂] and [HHb] in the right and left lateral prefrontal cortices (PFC) with a sampling frequency of 10 Hz. Behavioral performance was assessed by response time (RT in ms) and response accuracy. Finally subjective perceived difficulty (SPD) was assessed by the DP-15 [3].

Behavioral data analysis: First, repeated measures ANOVAs were conducted on RT and SPD during both control conditions (0-back1 vs. 0-back2). Next repeated measures ANOVAs were performed on RT and SPD data as a function of complexity (0-back2 vs. 1-back vs. 2-back vs. 3-back).

fNIRS data processing and analysis: The fNIRS signals were filtered with a Gaussian average filter of 1 s. To determine the level of activation, the area under the curve (AUC) [4] was calculated for [HbO₂] and [HHb] for each experimental condition. Statistical analyses followed the same procedure as for behavioral data.

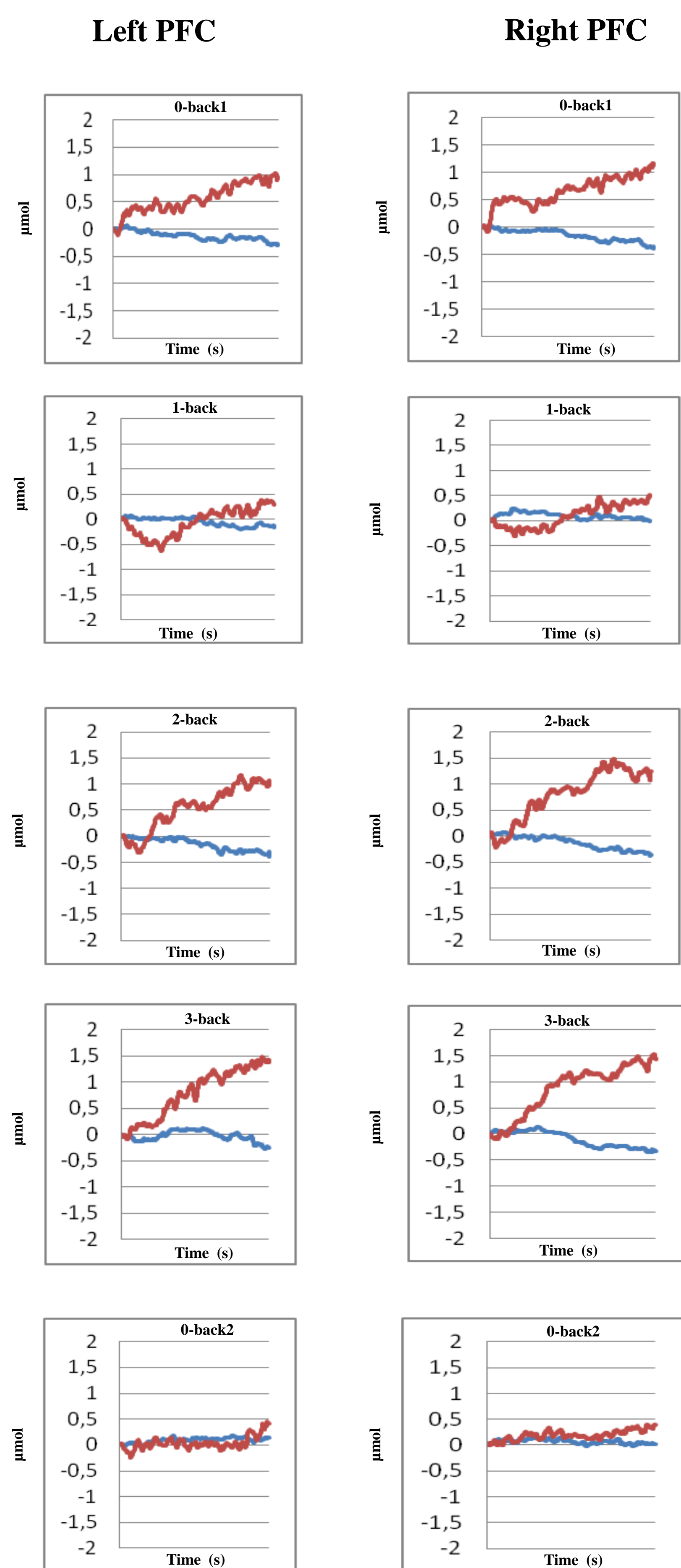


Figure 1: Grand mean of the hemodynamic patterns ([HbO₂] in red and [HHb] in blue)

RESULTS

Effect of the control task

Table1. Evolution of subjective and behavioral data as a function of both control conditions

	0-back1	0-back2	p value
RT (ms)	413.3±55.3	366.7±43.4	p < 0.001
Accuracy (proportion)	0.98±0.02	0.99±0.01	p = 0.24
SPD (1-15)	3.3±2	2.4±1.1	p = 0.03

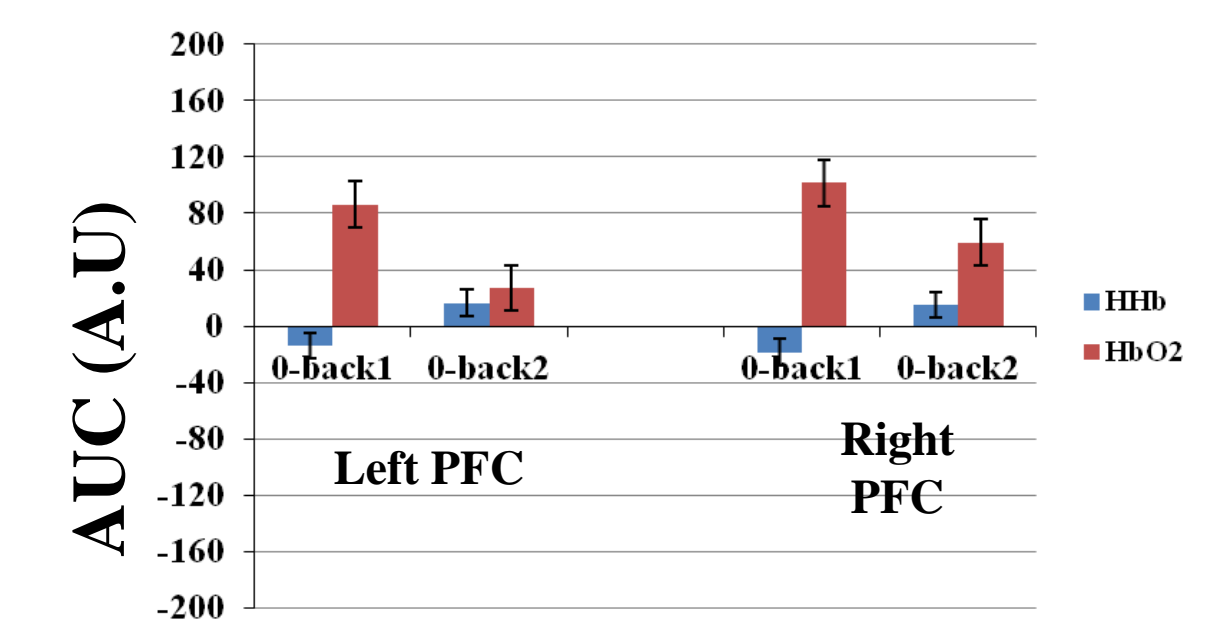


Figure 2: Evolution of the hemodynamic patterns as a function of repetition

The analysis showed that SPD and RT decreased as a function of repetition. However the decrease of [HbO₂] during 0-back2 was close to being statistically significant (p=0.054). Thus, the 0-back2 was chosen as a control condition to investigate mental-load effect on behavioral and hemodynamic data.

Effect of mental load

Table 2. Evolution of subjective and behavioral data as a function of mental-load

	0-back2	1-back	2-back	3-back
RT (ms)	366.7±43.4	404.3±73.6	517.4±152.9‡	592.7±183.6‡
Accuracy (proportion)	0.99±0.01	0.98±0.02	0.93±0.06‡	0.85±0.06‡
SPD (1-15)	2.4±1.1	4.4±2.1‡	7.7±1.6‡	10.7±2‡

‡: significant difference compared with the 0-back2

The analysis showed that SPD increased during 1,2,3-back compared to 0-back2. Behavioral performance (RT and Accuracy) decreased also as a function of mental-load. This decrease was significant during 2,3-back compared to 0-back2. These results indicated that the participants were less accurate and slower to respond when the task became more complex.

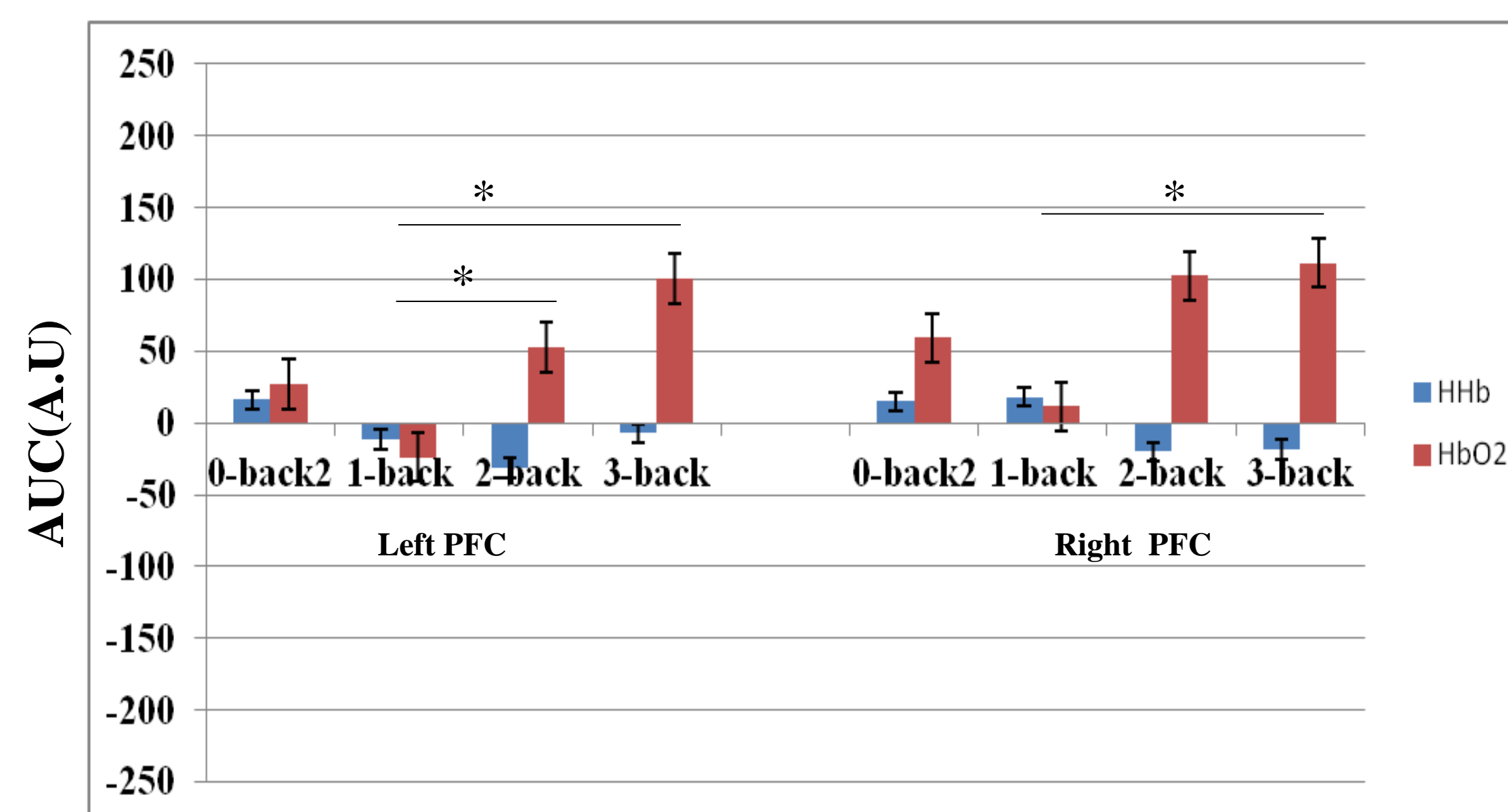


Figure 3 : Evolution of the hemodynamic patterns as a function of mental-load

The analysis showed main effects of mental-load [F(3,51)=4.77; p=0.005; η²=0.21] and of hemisphere [F(1,17)=6.32; p=0.022; η²=0.27] on changes of [HbO₂]. These results indicated that [HbO₂] was minimal during 1-back and increased during 2-back and 3-back on the right and left PFCs. However [HbO₂] increased more in the right hemisphere than in the left hemisphere. Finally these variations of [HbO₂] during 1-back were less prominent compared to 0-back2 even if this difference was not statistically significant.

Correlational analysis

Correlational analyses showed a positive correlation between changes in [HbO₂] and SPD as a function of the mental-load in the right PFC (r=.32; p=0.005) and the left PFC (r=.33; p=0.003). The same results were observed between changes in [HbO₂] and RT in the right PFC (r=.26; p=0.024) and the left PFC (r=.24; p=0.038).

DISCUSSION & CONCLUSION

Our findings highlight the importance of performing at least two measures of the control condition to ensure that the data from the control condition were stabilized.

The behavioral findings confirmed the previous studies by showing that the increase in mental-load induced a significant decrease of behavioral performances (RT and SPD) [1,2]. The analyses of the hemodynamic parameters showed that [HbO₂] increased bilaterally in the PFC as a function of complexity. However, the activations were prominent in the right PFC. Indeed, from the 2-back condition, activations reached their maximum in the right hemisphere while on the left hemisphere, activations continued to increase to reach their maximum value at the 3-back condition.

Furthermore, we observed positive relationships between behavioral data and PFC activations. These relationships indicated that when the task became more difficult, participant's PFCs activations increased in order to perform the task, while their behavioral performances decreased significantly.

To conclude, our results confirmed the effect of mental-load on the evolution of PFC activations and behavioral performance during an updating of working memory task, and the ability of the fNIRS to discriminate brain activations as a function of mental-load.

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