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Comparing EEG on interaction roles during a motor task

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Synopsis

This study compared the electroencephalography (EEG) activity of leaders who moved their hands and followers who followed the leader's movements. Such interaction is common in hyperscanning studies, but the influence of the leader and follower roles on EEG activity has scarcely been investigated. The log band power (LBP) and relative power level (RPL) were compared in theta and alpha bands. As a result, we found that LBP and RPL were higher in the theta band for the follower, which could be related to a greater cognitive load for the follower. The alpha band presented opposite patterns in LBP and RPL. LBP was higher in alpha for the follower, whereas the RPL was lower. RPL indicates that the alpha power among different bands is lower for the follower, which can be related to attentional suppression in alpha, although the absolute power is higher in the follower. This study indicates that different cognitive workloads are involved depending on the role of the interaction.

Background

In social interaction, two roles can be assigned: leaders and followers, depending on who initiates the movement and who follows their partner (Yun et al., 2012). Regarding leader-follower, Tomyta et al. found higher ϕ_1 [10-12] Hz for the leader and higher ϕ_2 [12-13] Hz for the follower during a motor tapping task (Tomyta et al., 2023). They argue that followers' mirror neurons were more activated to keep partners' pace and that leaders' mirror neurons were more deactivated, although another study did not observe such results (Hirao and Masaki, 2021). Different frequency bands could also be involved, as they may require different levels of cognitive workload to keep their pace or their partner's pace. To assess the neurophysiological differences in leader-follower, we compared their EEG using band power in a wide frequency range to characterize within-brain activity specific to interaction roles.

Methods

15 dyads (27.8 ± 5 years, 6 females) participated in this experiment, and 11 were of the same gender. Two participants were face-to-face in a virtual environment. One participant was assigned a leader or follower role. The leader was instructed to move their left or right hand in the air, and the follower followed the leader's movement using the opposite hand. This study was approved by the ethical committee from Inria (n° 2023-38), and all participants signed informed consent. Results on the influence of two embodiment conditions on interaction were already submitted for publication.

EEG data was collected from 16 electrodes using g.USBAMP. For pre-processing, EEG data was band-pass filtered within [0.5-40] Hz. Afterward, noise components, such as heartbeat, eye blinking, and muscular components, were removed via independent component analysis (ICA) (Delorme et al., 2007). We then calculated the log band power (LBP) and relative power level (RPL) from 1-second epochs for theta [4-7] Hz, alpha [8-13] Hz, and low beta [14-20] Hz bands to compare leader-follower roles. Absolute band power was obtained by integrating Welch's power

spectrum density (PSD) within each frequency (Welch, 1967). Then, LBP was obtained by taking the logarithm, and RPL was calculated by dividing the total band from each band to compare normalized values across participants (Ahn et al., 2013), which can be obtained below:

$$RPL_f = \frac{Power_f}{Power_{theta} + Power_{alpha} + Power_{low-beta}}$$

Where f indicates theta, alpha, and low-beta frequency bands.

As the main interest of the current study is to investigate the influence of leader-follower roles, the left and right-hand blocks and two visualization conditions were averaged. Participants performed both roles, so the same roles were concatenated. We compared the band power during leader and follower movement blocks through paired sample t-tests.

Results

Figure 1 represents LBP/RPL from leaders' minus followers'. For LBP, we observe in all bands a higher power for followers. After Bonferroni correction, the theta band showed significantly higher power along all electrodes, and the alpha band showed significantly higher power around central electrodes. The beta band showed significantly higher power around the right pre-frontal and frontal electrodes. This might be related to ocular activity, despite ICA components cleaning.

The RPL showed the same trend for the theta band, i.e., higher power observed for followers. However, the alpha band showed opposite results, indicating higher power for leaders around fronto-central electrodes, but the significance does not withhold multiple comparison corrections. For the beta band, there was no significant difference in RPL, but the opposite pattern is shown in the posterior areas.

Leader - Follower

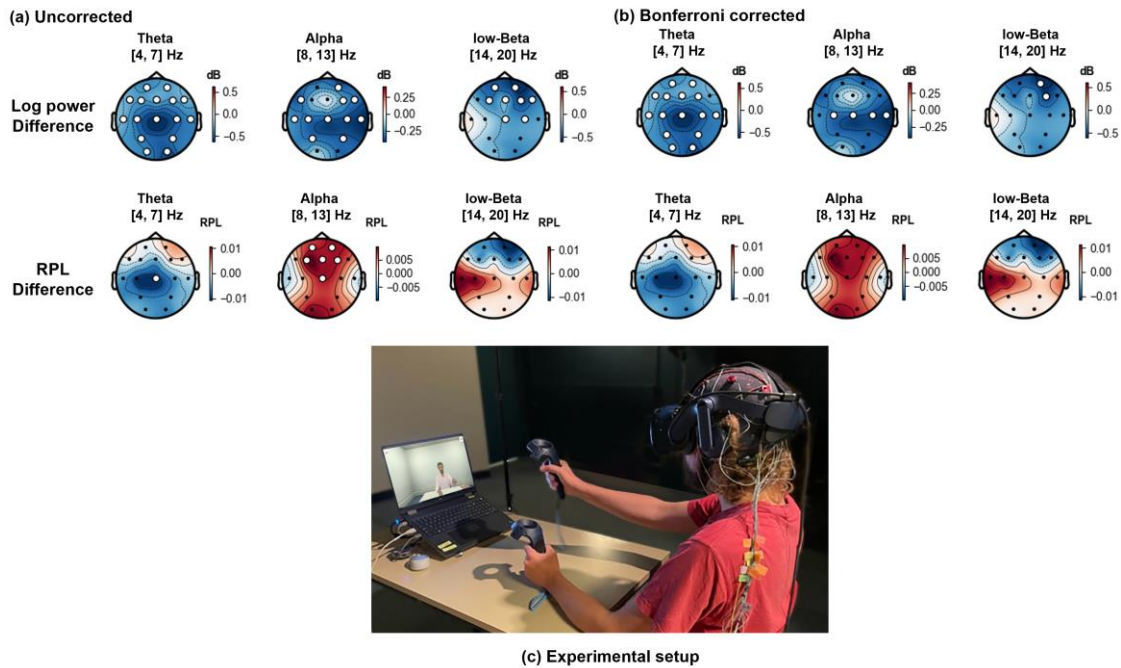


Figure 1. EEG band power difference between the leader and follower roles in LBP and RPL. White electrodes indicate significant differences: (a) uncorrected and (b) Bonferroni corrected. The blue areas indicate higher band power while performing as a follower than a leader, and the red areas indicate the opposite.

Discussion

This study compared EEG band power depending on interaction roles in a motor task. As a result, LBP and RPL showed higher power in the theta band for the follower, while the alpha band showed the opposite pattern between the two measures. For the theta band, a previous study reported that increased theta was related to increased involvement of cognitive resources, leading to higher cognitive workload (Puma et al., 2018). Thus, it may indicate that followers require more cognitive workload than leaders.

The alpha band showed a higher LBP but lower RPL for the follower. Regarding the two measures, the LBP can vary across participants due to the high variability of EEG activity across participants, although a logarithm could reduce power variation (Grandchamp and Delorme, 2011). The grand-averaged power showed higher band power over the theta, alpha, and beta bands. It may be caused by globally increased power due to leader-follower dynamics, such as task orders and different motion artifacts. In contrast, the RPL could be less affected by magnitude as it is normalized by total band power, which could facilitate comparative analysis by reducing EEG variability (Ahn et al., 2013). The current result, i.e., lower alpha RPL for followers, may be related to an increase in attentional suppression (Foxe and Snyder, 2011).

To sum up, this study identified different EEG activities between leader-follower roles during motor tasks. Current results indicate different cognitive and attentional resources depending on interaction roles. An in-depth investigation is required to clarify whether external factors are

involved in this difference using motion data and magnitude-free metrics, such as phase synchronization between intra- and inter-brain activities.

Disclosures

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