Neural responses to spontaneous blinking capture differences in working memory load: Assessing blink related oscillations with N-back task

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Background

With the increasing complexity and automation of modern life, there are significant demands on the brain to simultaneously monitor and perform complicated tasks while processing multi-sensory inputs within complex environments. This is especially true in aviation, where pilots must monitor and interact with cockpit displays and aircraft controls to conduct a safe and effective flight operations (Ghosh Hajra et al. , 2020; Law et al., 2020). Given the need to better facilitate human cognitive performance in these settings, several methods have been developed to assess brain function. One approach utilizes questionnaire-based rating scales like the NASA-TLX (Cha et al., 2018) to measure an individual's experience during a task; however, these tests are subjective and only indirectly assess brain function. Other techniques employ more objective brainwave metrics such as event-related potentials derived from electroencephalography (EEG), which measure brain responses elicited by external sensory stimuli (Dehais et al., 2019). Nonetheless, this requires that a secondary task (e.g. auditory stimulus) be superimposed on the existing primary task (e.g. flight maneuvers), which may interfere with primary task performance and compromise measurement fidelity. A better approach is needed that can provide objective measures of brain function without interfering with primary task performance.

Blink-related oscillations (BROs) are brainwave responses that follow spontaneous blinking (distinct from the oculomotor effects), and represent environmental monitoring and awareness processes as the brain evaluates new visual information that appears after eye re-opening (Liu et al., 2017). Although blinking has traditionally not been associated with cognitive processing, recent behavioural studies have suggested a link between blinking and cognition (e.g. we blink at the ends of sentences while reading (Orchard & Stern, 1991) and during speaker pauses while listening to speech (Nakano & Kitazawa, 2010)). In line with such evidence, the neurophysiological BRO responses have been shown to index a broad range of neural processes spanning sensation, information processing, and memory (Liu et al., 2018). Crucially, previous studies have shown that BRO responses are also dynamically modulated under a variety of task conditions including rest (Liu et al., 2017), cognitive loading (e.g. mental calculation; Liu et al., 2018), and different sensory environments (e.g. auditory vs visual inputs; Liu et al., 2020). These results suggest that the brain not only actively processes information with each blink, but BROs may also be used to evaluate brain function across a variety of task conditions through blinking – without interfering with the underlying task.

To develop a BRO-based brain function assessment tool deployable to complex naturalistic settings, it is essential to first ensure that BRO responses are present and detectable in tasks that more closely resemble these settings. As no study to date has investigated BRO responses in dynamic task conditions containing both cognitive loading and sensory stimulation, this study was undertaken to examine BROs during a complex working memory task with simultaneous visual inputs. In particular, we evaluated BRO responses during the performance of an N-back task as it activates a network of brain regions including the frontal and parietal cortices (Owen et al., 2005), and entails neurocognitive processes including sensory processing, working memory storage and updating, attentional mechanisms, motor response, and inhibitory processes among others (Costers et al., 2020; Watter et al., 2001).

Methods

This study utilized open access EEG data recorded during an N-back task with visually presented letter stimuli (N=26 healthy adults, age 26.1 ± 3.5, 17 female; Shin et al., 2018). Data were denoised via independent component analysis, and spontaneous blink instances were identified using an established convolution-based template matching procedure (Liu et al., 2017, 2018; Liu et al., 2019). Denoised data were filtered to the delta frequency band (0.5-4Hz), and signals from the Pz and POz channels were averaged together (Liu et al., 2020). Data were segmented into 3-s epochs centered on the latency of blink maximum, and averaged across trials to derive BRO responses. Mean amplitudes were then computed over windows of interest spanning the two post-blink peaks (P1 [80 to 180ms] and P2 [280 to 420ms]), as well as the pre-blink baseline (-1300 to -1100ms). Overall effects were assessed using a two-way repeated-measures analysis of variance (ANOVA), with 'time' (i.e. baseline, P1, P2) and 'task' (i.e. 0-back, 3-back) as within-subject factors. Specific blink-related effects were examined separately for each task using repeated-measures ANOVA across time, with Bonferroni correction for post-hoc multiple comparisons. Additional task-related effects were evaluated using a paired t-test for each time interval. Finally, Pearson correlations were computed to examine the relationship in BRO effects across tasks at the individual level.

Results

Results showed that BRO responses were present in both the 0-back and 3-back tasks, with two post-blink peaks P1 and P2 occurring at approximately 100ms and 340ms latencies, respectively (Figure 1a). This is consistent with prior studies reporting BRO responses in both resting and sensory stimulation conditions (Liu et al., 2020; Liu et al., 2017). The waveforms also exhibited narrow 95% confidence intervals in both N-back tasks (Figure 1c), suggesting the response was relatively consistent across individuals. Additionally, the magnitudes of both P1 and P2 peaks were significantly increased compared to baseline in both tasks ($p<0.001$ for both peaks in 0-back, $p<0.01$ for both peaks in 3-back), suggesting that blinking induced significant increase in neural activity during N-back task performance (Figure 1b). Comparison between tasks showed that BRO amplitudes were lower in 3-back compared to 0-back for P2 ($p<0.001$), while the reduction was not significant in P1. On the other hand, the peak-to-peak amplitude was not different between the two N-back conditions, suggesting that the increase in workload for 3-back compared to 0-back led to a systematic shift in BRO response rather than a reduction in P2 amplitude alone. Nonetheless, BRO amplitudes were strongly correlated between the 0-back and 3-back tasks for P2 ($r = 0.695$, $p<0.001$) but not P1 ($r = 0.171$, $p = 0.404$), suggesting that the between-task relationships in BRO amplitudes were more consistent across individuals for P2, while P1 showed more varied responses. Together, these results showed that BRO responses exhibited significant differences that reflected the increase in working memory load between the 0-back and 3-back tasks.

Conclusion

This study investigated blink-related oscillations using a visual n-back paradigm, and is the first demonstration of BRO responses under dynamic, complex task conditions with simultaneous working memory and visual stimulation demands. Our results showed that BRO responses were not only present during the n-back task, but the response amplitudes were also dynamically modulated by differential workload between the 0-back and 3-back conditions. These findings suggest that blink-related neural processing reflects underlying differences in cognitive workload, and BRO responses may provide a promising new avenue for assessment of cognitive state in naturalistic settings.

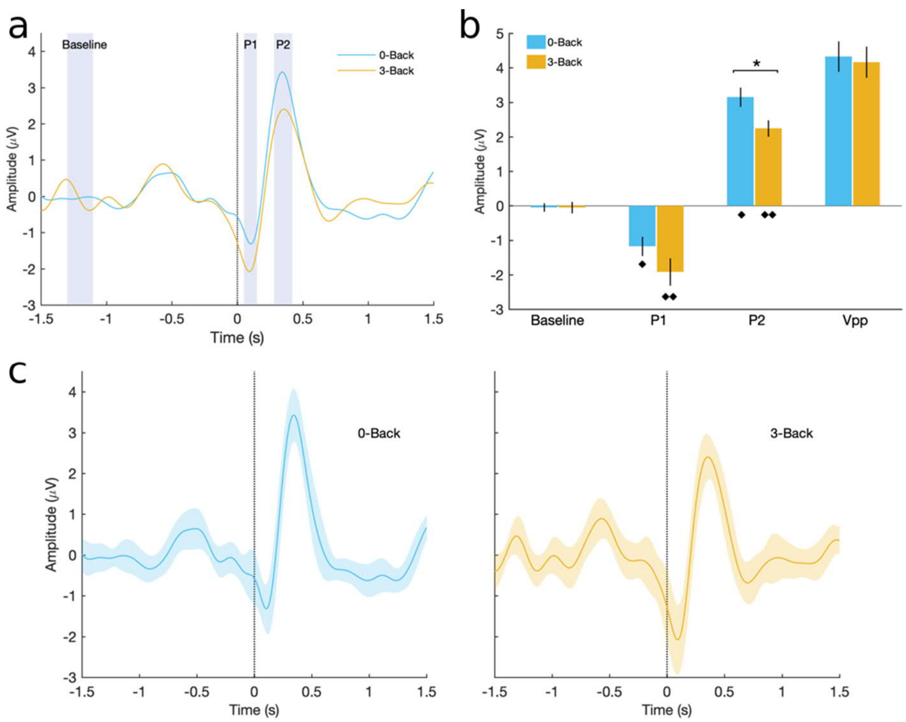

Figure 1. Time-domain BRO results after pooling together Pz and POz channels. a) Grand-averaged BRO waveforms across subjects. Black dotted line at time 0 denotes the latency of blink maximum. Shaded regions denote windows of interest spanning the two post-blink peaks (P1 and P2) and pre-blink baseline. b) Mean amplitudes within windows of interest, computed at the individual level and presented as mean $\pm$SE across participants. Vpp = peak-to-peak amplitude. ♦p<0.001 compared to baseline; ♦♦p<0.01 compared to baseline; *p<0.001 as indicated. c) Grand-averaged waveforms overlaid with 95% confidence intervals.

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