Figures and figure supplements

Age-dependent electroencephalogram (EEG) patterns during sevoflurane general anesthesia in infants

Laura Cornelissen, et al.
Figure 1. Experiment design. (A) Experiment timeline: schematic time-course of end-tidal sevoflurane concentration during the awake phase, induction, MOSSA (Maintenance of Surgical State of Anesthesia), and emergence phases of general anesthesia. Electroencephalogram (EEG) data from individual recording electrodes were analyzed post hoc for the awake brain state prior to anesthesia (shown in green), and two phases of general anesthesia (i) MOSSA (shown in red), and (ii) emergence from general anesthesia (shown in blue). (B) EEG montage used (modified international 10/20 electrode placement system).

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**Figure 2.** Study profile. Parents of 51 infants were approached and 36 consented. Five EEG recordings were excluded from the final analysis because of technical failures (n = 4) or a clinical event (n = 1; local anesthetic toxicity prior to surgical incision). For MOSSA analysis, data are presented from 30 EEG recordings (0–3 months, n = 11; 4–6 months, n = 19); for awake analysis, 19 infants were included (0–3 months, n = 7; 4–6 months, n = 12); and for emergence from general anesthesia analysis, 24 infants were included (0–3 months, n = 8; 4–6 months, n = 16).

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**Figure 3.** Frontal spectrograms during MOSSA. Individual infant EEG spectral power for frequencies from 0 to 30 Hz (left hand axis) during a 5-min period of MOSSA. Frontal spectrograms for infants at 0–3 months of age are shown for (A) individual infants and (B) group-median average. Frontal spectrograms for infants at 4–6 months of age are shown for (C) individual infants and (D) group-median average. F7 used with nearest neighbor Laplacian referencing.

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Figure 4. Frontal EEG power is greater in infants 4–6 months of age across all frequencies during MOSSA. (A) Frontal group-median power spectra (solid line, median; shaded area, 25th–75th percentile) across the 0–30 Hz-frequency band showing increased power in infants 4–6 months of age across all frequencies. (B–E) Differences in frontal group-median power spectra presented with 95% CI from bootstrap analysis (pink line, 97.5th percentile; green line, 2.5th percentile) comparing infants at 0–3 month to 4–6 months of age. (B) Power difference in slow and delta frequency range, 0–4 Hz, (C) theta, 4–8 Hz, (D) alpha, 8–12 Hz, and (E) beta, 12–30 Hz. F7 electrode presented using nearest neighbor Laplacian referencing. DOI: 10.7554/eLife.06513.007
Figure 4—figure supplement 1. Frontal EEG spectral properties in infants anesthetized under a uniform end-tidal sevoflurane concentration (1.8%). Group-averaged frontal power spectrograms in infants (A) 0–3 months of age, and (B) 4–6 months of age (C) Frontal group-median power spectra (solid line, median; shaded area, 25th–75th percentile) across 0–30 Hz frequencies. (D–G) Differences in group-averaged frontal power spectra presented with 95% CI from bootstrap analysis (pink line, 97.5th percentile; green line, 2.5th percentile) comparing infants at 0–3 months to infants at 4–6 months of age. F7 electrode presented using nearest neighbour Laplacian referencing. etSEVO: end-tidal sevoflurane concentration. Epoch size of 30 s is used. DOI: 10.7554/eLife.06513.008
Figure 5. Spatial distribution of spectral power during MOSSA. Group-median spectrograms at each recording electrode location across the scalp in infants at (A) 0–3 months (n = 11) and (B) 4–6 months (n = 19).
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Figure 6. Topographic EEG maps of spectral power for distinct frequency bands during MOSSA. Topographic EEG maps detailing group-averaged power for each EEG frequency band in infants aged (A) 0–3 months (n = 11) and (B) 4–6 months (n = 19). Slow-wave activity is distributed across the scalp in both postnatal age groups, while alpha activity is present to a greater degree in infants 4–6 months postnatal age. Legend for A and B is shown by the color bar. DOI: 10.7554/eLife.06513.010
Figure 7. Frontal predominance of alpha power is low during MOSSA in infants 0–6 months of age. Frontal group-median power spectra (solid line, median; shaded area, 25th–75th percentile) showing similar EEG power across all frequencies in frontal and occipital channels in infants aged (A) 0–3 months (n = 11) and (B) 4–6 months (n = 19). Differences in frontal group-median power spectra presented with 95% CI from bootstrap analysis (pink line, 97.5th percentile; green line, 2.5th percentile) between frontal and occipital channels during MOSSA in infants aged (C–F) 0–3 months and (G–J) 4–6 months. A small but significant increase in frontal alpha power compared to occipital alpha power begins to emerge at 4–6 months of age. FPz and Oz electrodes presented using nearest neighbor Laplacian referencing.

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Figure 8. Frontal alpha coherence is absent during MOSSA in infants from 0 to 6 months postnatal age. Group-averaged frontal spectrograms in infants aged 0–3 months at (A) Left—F7, and (B) Right—F8, and infants aged 4–6 months (C) F7, and (D) F8. Relative group-averaged frontal coherogram (F7–F8) for infants aged (E) 0–3 months and (F) 4–6 months age. (G) Frontal group-median coherence (solid line, median) showed similar coherence across 0.1–30 Hz frequency bands at all postnatal ages.

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Figure 9. Global coherence is low across all frequencies during MOSSA in infants from 0 to 6 months of age. Topographic EEG maps detailing group-averaged global coherence for each EEG frequency band in infants (A) 0–3 months (n = 11) and (B) 4–6 months (n = 19) of age. (C) Group-median global coherence spectra (solid line, median; shaded area, IQR) show similar low coherence across 0–30 Hz frequency bands at all ages during MOSSA. DOI: 10.7554/eLife.06513.013
Figure 10. Frontal EEG power changes between the awake state and MOSSA. (A) Group-averaged frontal power spectra (solid line, median; shaded area, 25th–75th percentile) show similar EEG power during the awake state (prior to anesthesia) and MOSSA in infants aged 0–3 months across all frequencies ($n=7$). (B) Group-averaged frontal power spectra show increased theta, alpha, and gamma oscillations during MOSSA in infants 4–6 months of age ($n=12$). Differences in group-averaged frontal power spectra presented with 95% CI from paired bootstrap analysis (pink line, 97.5th percentile; green line, 2.5th percentile) between Awake and MOSSA in infants (C–F) 0–3 months and (G–J) 4–6 months of age. F7 electrode presented using nearest neighbor Laplacian referencing. Epoch size of 11 s is used for awake and MOSSA states.

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Figure 10—figure supplement 1. Frontal EEG spectral properties in awake infants. Frontal group-median spectrograms in infants (A) 0–3 months, and (B) 4–6 months of age. (C) Frontal group-median power spectra (solid line, median; shaded area, 25th–75th percentile) across 0–30 Hz frequencies. (D–G) Differences in frontal group-median power spectra presented with 95% CI from bootstrap analysis (pink line, 97.5th percentile; green line, 2.5th percentile) comparing infants aged 0–3 months to infants 4–6 months of age. $F7$ electrode presented using nearest neighbor Laplacian referencing. Epoch size of 11 s is used.
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Figure 11. End-tidal sevoflurane concentration associated spatial EEG power and body movement during emergence from sevoflurane general anesthesia. (A) End-tidal sevoflurane concentration increments from MOSSA to emergence from general anesthesia for infants 0–3 months (n = 8), and (B) 4–6 months of age (n = 16), and (C) the corresponding percentage of infants who displayed gross body movement MOSSA.

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Figure 12. Frontal EEG power changes between MOSSA and body movement. (A) Frontal group-median power spectra (solid line, median; shaded area, 25th–75th percentile) show similar EEG power during MOSSA and after first body movement in infants aged 0–3 months across all frequencies. (B) Frontal group-median power spectra show increased theta and alpha oscillations during MOSSA in infants aged 4–6 months. Differences in frontal group-median power spectra presented with 95% CI from bootstrap analysis (pink line, 97.5th percentile; green line, 2.5th percentile) between MOSSA and emergence after first body movement in infants (C–F) 0–3 months and (G–J) 4–6 months of age. F7 electrode presented using nearest neighbor Laplacian referencing. DOI: 10.7554/eLife.06513.017