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EEG variables as measures of arousal during propofol anaesthesia for general surgery in children: rational selection and age dependence

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Background. Clinical benefits of measuring processed EEG during anaesthesia in adults, such as improved recovery and reduced risk of awareness, may also be valid in children. This study evaluated a rational selection of EEG variables as measures of arousal during surgical anaesthesia in children.

Methods. Sixty children undergoing surgical anaesthesia with propofol and remifentanil were enrolled. The performance of 33 single EEG variables and bispectral index (BIS) was assessed by simultaneous analysis of prediction probability (Pk) of Children's Hospital of Wisconsin Sedation Scores and their signal-to-noise ratio (SNR). Variables performing best in Pk and SNR analysis were selected as potential measures of arousal. Their performance was investigated in five age groups, 0–1, 1–2, 2–5, 5–8, and 8–13 yr.

Results. Single EEG variables such as relative power from frequency bands 13–20 and 20–26 Hz, SEF95, and approximate entropy performed best with Pk>0.59 and SNR>5.50. The Pk and SNR of BIS were 0.71 and 15.76, respectively. Their performance was significantly better in children aged 1–13 yr than in 0–1 yr.

Conclusions. BIS may provide a measure of arousal during propofol anaesthesia in children, but its accuracy is less in infants younger than 12 months. Single EEG variables such as high-frequency components of EEG, SEF95, and approximate entropy may be of limited value to detect arousal in the individual paediatric patient.

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Monitoring general anaesthesia by the processed spontaneous EEG is established in adults. Potential benefits include improved hypnotic drug titration, faster recovery times, and reduced risk of awareness.[1–3] The clinical benefits derived from measuring processed EEG during anaesthesia may also be valid in children. Recent work describing EEG changes in paediatric patients during general surgery considers anaesthesia with inhaled agents.[4–9] The few reports regarding processed EEG during total i.v. anaesthesia in children are limited to diagnostic procedures.[10 11]

The suitability of processed EEG to measure the level of arousal during anaesthesia is mainly assessed by the association with observed clinical conditions in terms of a response to stimulus test,[12] such as response to verbal command[13] or to noxious stimuli of increasing intensity,[14] and expressed as the prediction probability Pk.[15] The Children's Hospital of Wisconsin Sedation Scale (CHWSS) is an observational rank scale that combines response to verbal and noxious stimuli of increasing intensity.[16] It provides a classification from 'anxious, agitated or in pain', as 'inadequate sedation', to 'unresponsive to painful stimulus', as 'anaesthesia'.

Although the association with observed clinical conditions reflects the relation between the value of the EEG variable and the observational score, the time for estimation of the EEG variable also has some influence on the clinical usefulness, because a faster estimation reflects more closely the rapid changes of the cerebral activity.

Since estimation time mainly depends on the smoothing interval required for an appropriate representation of the trend, the EEG variable should have a high signal-to-noise ratio (SNR), because the higher this ratio the shorter the required smoothing time.

This study aimed at quantifying the performance of 33 single EEG variables and the bispectral index (BIS) as a composite variable by simultaneous analysis of the prediction probability Pk of CHWSS scores and the estimated SNR during propofol-based anaesthesia supplemented by remifentanil in children. Variables that performed best in both categories were selected as potential measures of arousal for paediatric anaesthesia. Since recent pharmacodynamic investigations reported an age-dependent EEG effect during general anaesthesia,[4 8] the impact of age was also studied.

Methods

Patients

After approval by the ethic committee and after informed parental consent, the anonymous recordings of EEG, ECG, and arterial pressure from children aged 0–13 yr who underwent elective urological or abdominal surgery under general anaesthesia at the University Hospital Erlangen were considered for this study. Data from children having an ASA physical status III or higher, recent administration of drugs affecting the central nervous system and being not part of the anaesthetic procedure, psychiatric, or neurological diseases, and allergy to adhesives or indication to rapid sequence induction were excluded.

Anaesthetic procedure

All children received 30 min before arrival in the operating room midazolam 0.5 mg kg^{-1} p.r. (up to 30 kg body weight) or 0.4 mg kg^{-1} p.o. (maximum dose 15 mg) as premedication and EMLA-crème on the back of both hands and feet (when necessary) for the peripheral i.v. puncture. In the operating room, the EEG electrodes were placed, an i.v. cannula was introduced, and infusion of lactated Ringer's solution was started approximately 10 min before induction of anaesthesia. After preoxygenation via face mask, anaesthesia was induced with fentanyl 2 μg kg^{-1} i.v. followed 60 s later by lidocaine 0.5 mg kg^{-1} i.v. and propofol 3–4 mg kg^{-1} i.v., respectively. When patients stopped breathing spontaneously, the mask ventilation was started followed by the insertion of a laryngeal mask or an endotracheal tube under muscle relaxation with mivacurium 0.2 mg kg^{-1} i.v. The lungs were mechanically ventilated to maintain normocapnia and normoxaemia with a mixture of oxygen in air. During surgical procedure, the maintenance of anaesthesia was performed with an i.v. infusion of propofol 6–10 mg kg^{-1} h^{-1} and remifentanil 0.25–0.5 μg kg^{-1} min^{-1}. Drug dosing was conducted by the attending anaesthesiologist in order to maintain heart rate and mean arterial pressure within 20% of baseline values obtained before induction of anaesthesia. No further doses of neuromuscular blocking agents were administered. After skin closure, the infusion of anaesthetics was stopped and extubation was performed when the children were breathing regularly with a tidal volume >6 ml kg^{-1}. Postoperative analgesia was provided by i.v. infusion of acetaminophen 15 ml kg^{-1}, which was administered approximately 20 min before the end of the surgical procedure. With regain of apparent alertness, the monitors for vital functions and EEG were disconnected, and the children were transferred to the post-anaesthesia care unit.

Monitoring environment

In the operating room, non-invasive measurements of heart rate, arterial pressure, oxygen saturation, inspiratory oxygen, end-tidal carbon dioxide, and respiratory parameters were monitored with a SIEMENS SC 9000 monitor (Siemens Medical Systems, Inc., Electromedical Group, Danvers, MA, USA). The skin was prepared with alcohol at EEG electrode positions in order to maintain impedances <10 kΩ. Ambu Neurology electrodes (Ambu A/S, Ballerup, Denmark) were placed at Fp1, Fp2, and Fpz according to 10–20 system. The digitized EEG, obtained from the RAW EEG port of an Aspect A1000-monitor (128 samples s^{-1}; Fpz as GND; 50 Hz low pass filter; 0.5 Hz high pass filter; 50 Hz notch filter), and the processed BIS® (Aspect Medical Systems, Newton, MA, USA, Rev. 3.31, one value per second) were stored on a laptop computer synchronized to the data collection of vital parameters.

CHWSS assessment

The attending anaesthesiologist was blinded to BIS and estimated the level of consciousness using the CHWSS after applying the predefined stimuli described later. The CHWSS is rated from 0 to 6, where 6=agitated, anxious, or in pain without stimulus; 5=awake and calm without stimulus; 4=drowsy with eyes open or closed, easily aroused by mild or moderate verbal stimulus; 3=drowsy, arousable by loud verbal stimulus; 2=can be aroused to consciousness by raising the lower jaw or mask ventilation; 1=movement of extremities or head by raising the lower jaw or mask ventilation, intubation, or surgical stimulus; and 0=unresponsive to intubation or surgical stimulus.

The CHWSS estimation started 5 min before induction of anaesthesia and ended 5 min after regain of apparent alertness. Alertness after anaesthesia was defined as eye opening, purposeful movement, or phonation as appropriate for age. CHWSS scores were assessed every 30 s during induction and recovery, and every 2 min before induction and during maintenance of anaesthesia. During the induction period, the patient's name was moderately to loudly spoken near the patient's ear every 30 s until no reaction was present, followed by raising the lower jaw and insertion of a laryngeal mask or endotracheal tube as a stimulus of higher intensity. During the recovery period, skin suture, lower jaw test, and verbal stimuli were considered until regain of apparent alertness. The estimated CHWSS scores were stored online by a study nurse on the same laptop computer as for the heart rate, arterial pressure, and EEG recordings.

EEG processing

The digitized EEG was filtered between 0.5 and 47 Hz and then segmented into epochs of 2^{10} data points (8 s). Thirty-three single EEG variables were calculated from artifact-free, stationary EEG epochs. In addition, BIS values with an Artifact Flag of zero were also considered for further analysis. Smoothed values of each single EEG variable and BIS were estimated in each patient using the Nadaraya–Watson kernel smoother with automatic selection of an appropriate smoothing interval. A detailed description of the processing method and the estimated EEG variables are given in the Appendix at *British Journal of Anaesthesia* online.

Statistical analysis

The performance of each EEG variable and BIS was quantified by the prediction probability (Pk) and the SNR during the analysis period defined as 5 min before start of anaesthesia to 5 min after regain of apparent alertness. Also, the time required for estimation (TRE) was considered.

Jackknife estimates of Pk ($\hat{P}$kjack) and its standard error ($\hat{\sigma}_{Pkjack}$)[15] were obtained from the pooled data pairs (i.e. EEG variable value and corresponding CHWSS score) of all patients during the analysis period. The Pk takes values between 0 and 1, whereas 1 represents a perfect concordant and 0 a perfect discordant relationship between EEG variable values and CHWSS scores, i.e. they are rank ordered in the same and opposite direction, respectively (see Appendix online). The Pk equals 0.5 when the probability of concordance (or discordance) is no better than random guess. In case of a discordant relationship, i.e. Pk$\in$[0,0.5], the Pk was normalized by calculating $1-$Pk.[17] The ability of EEG variables and BIS to predict CHWSS scores, that is Pk was significantly different from 0.5, was assessed using the *t* statistic ($\hat{P}$kjack$-$0.5)/$\hat{\sigma}_{Pkjack}$.[15]

The SNR and TRE for each EEG variable and BIS were obtained by averaging the individual values of the patients. In each patient and for each variable, the SNR was computed as the ratio between the variance of the estimated variable values and the variance of the residuals. The residuals represent the difference between estimated and measured variables. The TRE equals the smoothing interval as calculated with the smoothing procedure (see Appendix online).

The estimated Pk and SNR values of all variables except BIS defined the Pk and SNR distribution, respectively. EEG variables were selected as suitable for measuring arousal during anaesthesia if the following criteria were simultaneously present: (i) Pk significantly different from 0.5; (ii) Pk greater than 75th centile of the Pk distribution; and (iii) SNR greater than 75th centile of the SNR distribution. Performance differences between selected variables were analysed separately for Pk and SNR values. Differences in Pk were assessed using a paired-data jackknife analysis with Bonferroni correction for multiple comparisons.[15] Differences in SNR were investigated by the Welch test.[18]

For evaluating the impact of age on performance or values of single EEG variables and BIS, the patients were divided into five age groups: 0–1, 1–2, 2–5, 5–8, and 8–13 yr. Pk differences between the age groups were assessed in each variable using a *t*-test on jackknife estimates with Bonferroni correction for multiple comparisons.[15] SNR and TRE differences and differences in baseline shift of heart rate and mean arterial pressure (i.e. ratio of values at CHWSS=0 to mean value at CHWSS=5) were investigated by the Welch test.

The statistical analysis was performed with Matlab (Version R14, The Mathworks Inc., Natick, MA, USA) and SPSS (Version 14.0.1, SPSS Inc., Chicago, IL, USA) at a significance level of α=0.05. Results are presented as mean (SE), except for Pk jackknife values, which are presented as estimate (SE). Owing to the exploratory character of the study design, no power analysis was performed before the investigation.

Results

Sixty children were enrolled in the study. Two children had incomplete CHWSS scores. The recording of ECG and arterial pressure failed in one child, and in another child, one-half of the EEG recording was disturbed by high-frequency diathermy and X-ray equipment. Therefore, further analysis was performed on data from the remaining fifty-six children aged 2 months to 13 years (Table 1). During anaesthesia with propofol and remifentanil, the shift in heart rate was −15.1% (−26.3% to −4.5%) of the baseline values measured before anaesthetic induction, whereas the shift in mean arterial pressure was −1.8% (−15.9% to 3.5%) of the baseline values (data presented as median and inter-quartile range). As depicted in Figure 1, the baseline shift in heart rate and mean arterial pressure was not significantly different between the age groups ($P\geq0.05$).

A total of 86 h original EEG signal were analysed. After automatic and visual signal preprocessing, approximately

Table 1 Patient's data in the different groups of age. Data for age are presented as mean (range), data for weight and height as mean (SD)

	Age group				
	0–1	**1–2**	**2–5**	**5–8**	**8–13**
n	5	12	15	12	12
Age (yr)	0.6 (0.2–0.9)	1.5 (1.0–1.9)	3.5 (2.3–4.5)	6.6 (5.1–7.9)	10.4 (8.4–12.6)
Weight (kg)	7.5 (2.3)	10.7 (1.5)	16.7 (6.3)	23.7 (4.9)	36.8 (11.4)
Height (cm)	65.5 (12.0)	81.3 (6.3)	102.7 (15.9)	120.3 (6.4)	144.0 (11.7)
Male/female	3/2	9/3	12/3	8/4	9/3

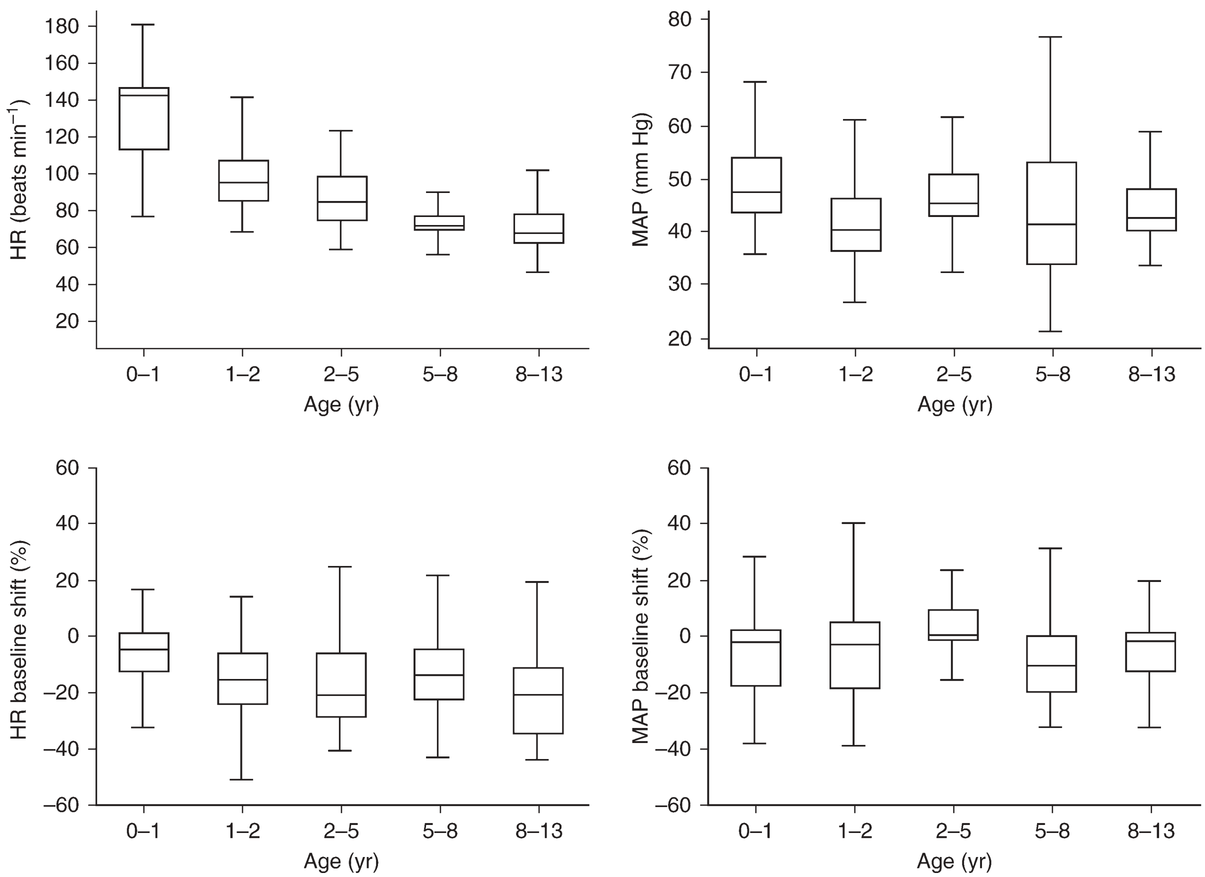

Fig 1 Box and whisker plot of heart rate (HR) and mean arterial pressure (MAP) during anaesthesia with propofol and remifentanil (CHWSS=0). Upper panels depict the absolute values in the five age groups; the lower panels show the relative shift in per cent related to the baseline values. Box lines, the lower quartile, median, and upper quartile values; box whiskers, lines from each end of the box for the extent of the rest of the data.

88% EEG and 12% artifact were identified. Burst suppression patterns (1% of EEG) were mainly identified at the end of the induction period in 60% (3/5), 42% (5/12), 40% (6/15), 42% (5/12), and 42% (5/12) of the patients in the age groups 1–5, respectively. Figure 2 depicts the representative EEG patterns from one 10-yr-old child assessed during different clinical states together with the original and estimated BIS values and the time course of four estimated single EEG variables.

The overall performance results are depicted in Figure 3. EEG variables such as absolute power from frequency bands 8–13, 13–20, and 32–47 Hz, relative power from frequency bands 8–13, 13–20, 26–32, and 32–47 Hz, beta ratio, SEF95, ratio of bispectrum 0.5–47 Hz to bispectrum 30–47 Hz, and approximate entropy predicted level of sedation and anaesthesia significantly better than chance alone ($P<0.05$) and achieved Pk values higher than 0.59 (i.e. 75th centile of Pk distribution). BIS achieved a Pk of 0.71. A SNR greater than 5.50 (i.e. 75th centile of SNR distribution) was obtained by variables calculated from relative power of frequency bands 13–20, 20–26, and 20–32 Hz, SEF50, SEF75, SEF90, SEF95, symbolic, and approximate entropy. BIS showed the highest SNR of 15.76.

The defined suitability criteria for EEG variables as measures of arousal were satisfied in the study population

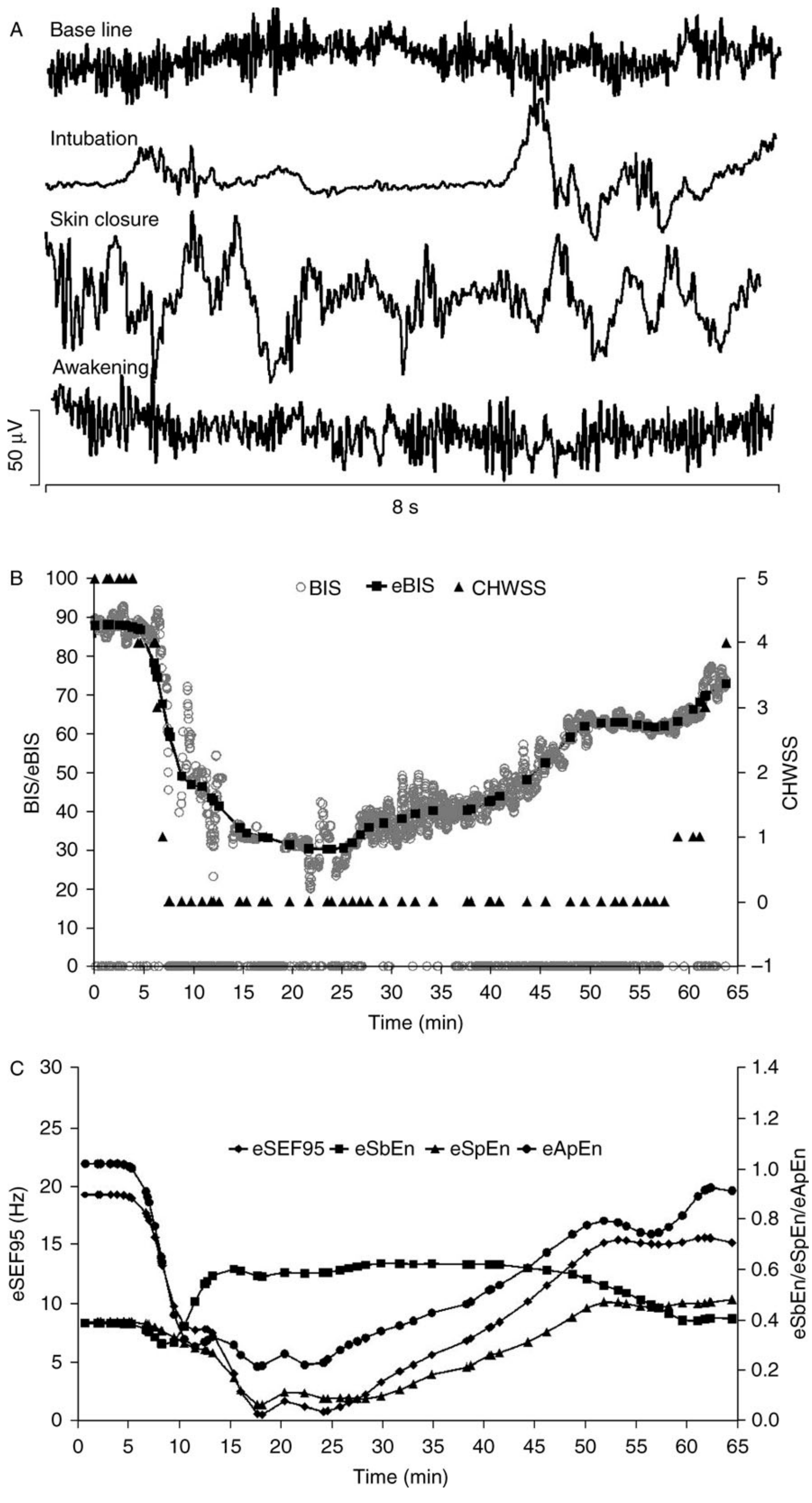

Fig 2 (A) EEG patterns during different clinical states from a 10-yr-old child. (B) Raw BIS (BIS) together with estimate values of BIS (eBIS) and CHWSS scores. Raw BIS values of 0 were artifacts. (C) Estimate values of SEF95 (eSEF95), symbolic entropy (eSbEn), spectral entropy (eSpEn), and approximate entropy (eApEn).

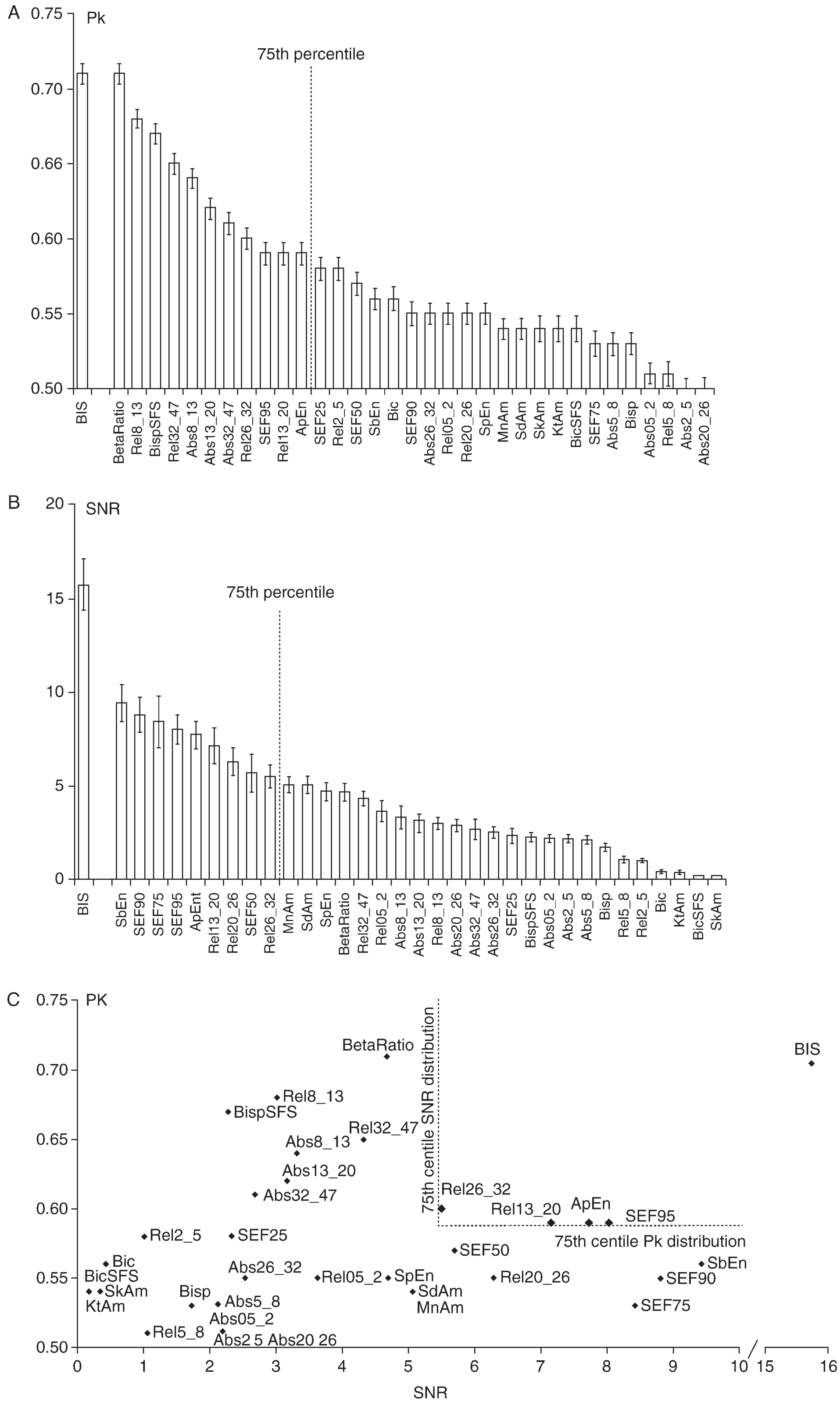

Fig 3 Prediction probability (Pk) and SNR of single EEG variables and BIS (A and B, respectively). Pk values are presented as estimate (SE); SNR values are presented as mean (SE). EEG variables for monitoring arousal are highlighted in the upper right corner of (C). 75th percentile, 75th centile of the corresponding distribution. MnAm, mean absolute amplitude; SdAm, standard deviation of amplitudes; SkAm, skewness of amplitude histogram; KtAm, kurtosis of amplitude histogram; SEF25–95, frequency below which 25–95% of spectral power resides; RelLF_HF, relative spectral power between low-frequency (LF) component and high-frequency (HF) component; AbsLF_HF, absolute spectral power between LF and HF; SbEn, symbolic entropy; SpEn, spectral entropy; ApEn, approximate entropy; Bisp, bispectrum; Bic, bicoherence; BetaRatio, log ratio spectral power 30–47 Hz to spectral power 11–20 Hz; BispSFS, log ratio bispectrum 0.5–47 Hz to bispectrum 40–47 Hz; BicSFS, log ratio bicoherence 0.5–47 Hz to bicoherence 40–47 Hz.

by relative power from frequency bands 13–20 and 26–32 Hz, SEF95, and approximate entropy. When compared with BIS, these variables had a lower prediction probability for the level of sedation and anaesthesia and also showed a lower SNR ($P<0.05$). SEF95 and approximate entropy had a better SNR than relative power from frequency bands 26–32 Hz ($P<0.05$), whereas the differences in Pk between the selected variables remained statistically not significant ($P\geq0.05$).

Figure 4 depicts the age-related performance of five single EEG variables and BIS. The Pk of relative power from frequency bands 13–20 and 26–32 Hz, SEF95, approximate entropy, and BIS was significantly lower in children less than 1 yr than in older children ($P<0.05$), except for BIS between children 0–1 and 5–8 yr. Interestingly, EEG variables such as power from frequency bands 0.5–2 and 2–5 Hz, SEF25, SEF50, SEF75, and spectral entropy predicted significantly better the level of sedation in children less than 1 yr than in older children ($P<0.05$). The Pk analysis within the age group 0–1 yr also revealed significantly higher Pk values for these variables than for relative power from frequency bands 13–20 and 26–32 Hz, SEF95, and approximate entropy (Pk<0.05). The SNR of relative power from frequency bands 13–20 and 26–32 Hz, SEF95, approximate entropy, and BIS were significantly lower in children aged 0–1 yr compared with children of older age groups ($P<0.05$). Also, the TRE of these variables were higher in children 0–1 yr than in older children, whereas the observed differences remained statistically not significant ($P\geq0.05$).

Although there was a considerable overlap in values of EEG variables between different CHWSS scores, the values during deep sedation and anaesthesia differed with age. This difference was more pronounced for symbolic entropy and BIS (Fig. 5) between children less than 1 yr and older children ($P<0.05$) than for relative power from frequency bands 13–20 and 26–32 Hz, SEF95, and approximate entropy ($P\geq0.05$).

Discussion

The present study aimed at quantifying the performance of 33 single EEG variables and BIS as measures of arousal during surgical anaesthesia with propofol and remifentanil in children. The performance was assessed by simultaneous analysis of the prediction probability (Pk) of CHWSS scores and the SNR. BIS and single EEG variables such as relative power from frequency bands 13–20 and 26–32 Hz, SEF95, and approximate entropy performed best in children aged 1–13 yr. However, they showed a lower performance in infants less than 1 yr. In this age group, changes in relative power from frequency bands 0.5–2 and 2–5 Hz, SEF25, SEF50, and SEF75 predicted better different levels of arousal than changes in relative power from frequency bands 13–20 and 26–32 Hz, SEF95, and approximate entropy. These findings are similar to the results of other investigations during paediatric anaesthesia with inhaled agents[5 8 9] and may be due to the immaturity of the EEG described for infants and young children: the dominant awake frequency increases from 5 Hz at 6 months through 6–7 Hz at 9 to 18 months and 7–8 Hz at 2 yr, reaching 9 Hz by 7 yr and 10 Hz by 15 yr, respectively.[19] Also, specific EEG patterns such as periods of EEG activity from 1 to 3 Hz or short bursts of 4–8 Hz activity have been associated with the transition between awake and asleep in children younger than 5 yr.[12]

Single EEG variables affected by propofol anaesthesia are similar in children older than 1 yr and in adults. A recent investigation in adult volunteers has shown that relative power from frequency bands 20–26 Hz, SEF95, and approximate entropy predicted at best nine clinical end-points observed at 17 different times during two consecutive propofol infusions.[20] The same EEG variables also achieved highest SNR values. Another investigation in adult patients during surgical anaesthesia with propofol and remifentanil identified the median frequency of the range from 8 to 30 Hz, the absolute power from frequency bands 21 to 30 Hz, and the approximate entropy as EEG variables that were able to differentiate between consciousness and loss of consciousness.[21]

In the present study, the BIS performed best when it was compared with single EEG variables. This may be explained by its composite nature out of three EEG derivatives combined in a proprietary algorithm. In the present study, two of these derivatives, namely ratio of power in fast and moderate frequencies (BetaRatio) and high bispectral power (BispSFS), showed Pk values greater than 75th percentile of the Pk distribution. These findings are in accordance with EEG investigations in adults during anaesthesia.[21 22] As demonstrated in a recent work, a composite EEG derivative can predict different clinical states of general anaesthesia better than single EEG variables.[23] The BIS also showed the highest SNR and lowest TRE compared with single EEG variables. These results indicate a higher degree of preprocessing, including smoothing.

The CHWSS is a validated observational score for children from birth to maturity.[16] It delineates boundaries between awake, sedation, and anaesthesia in response to verbal and noxious stimuli of increasing intensity. Therefore, the CHWSS measures the patient's level of arousal as a function of the applied stimuli and the effect concentration of administered sedatives and anaesthetics.[12] Since the values of the EEG variable were estimated at the time points of CHWSS assessment, that is after the arousal stimuli, normalized Pk values significantly greater than 0.5 in this investigation represent the ability of the EEG variable to reflect different levels of arousal.

A possible concern when investigating the ability of processed EEG to predict different levels of arousal as assessed by the observational score is the lack of

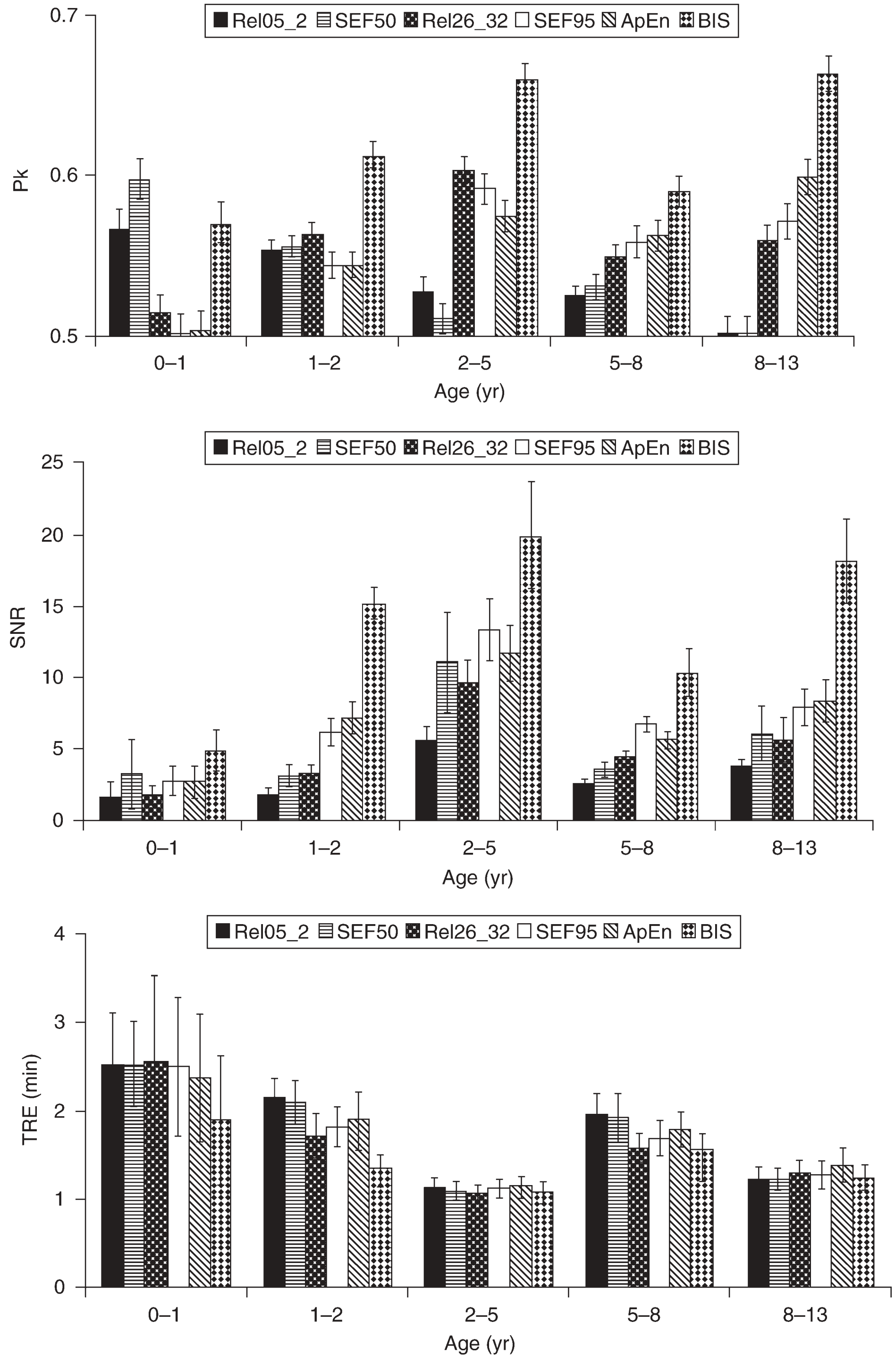

Fig 4 Performance of five single EEG variables and BIS in different age groups. Pk, prediction probability; SNR, signal-to-noise ratio; TRE, time required for estimation. Pk values are presented as estimate (SE); SNR and TRE values are presented as mean (SE). Rel05_2, relative power from frequency band 0.5–2 Hz; Rel26_32, relative power from frequency band 26–32 Hz; SEF50, frequency below which 50% of spectral power resides; SEF95, frequency below which 95% of spectral power resides; ApEn, approximate entropy; BIS, bispectral index.

information once the patient does not respond to the applied stimuli. This level of anaesthesia is represented by CHWSS=0 and may include different patterns of spontaneous EEG. For example, light propofol sedation combined with excessive opioid doses may produce delta activity in the spontaneous EEG, whereas propofol anaesthesia supplemented or not by an opioid may produce suppression of spontaneous EEG, and thus different values of the processed EEG. However, both regimens may suppress a patient's response to the same intensive surgical stimulus. In this investigation, the continuum of changes in the patient's level of arousal was divided into a

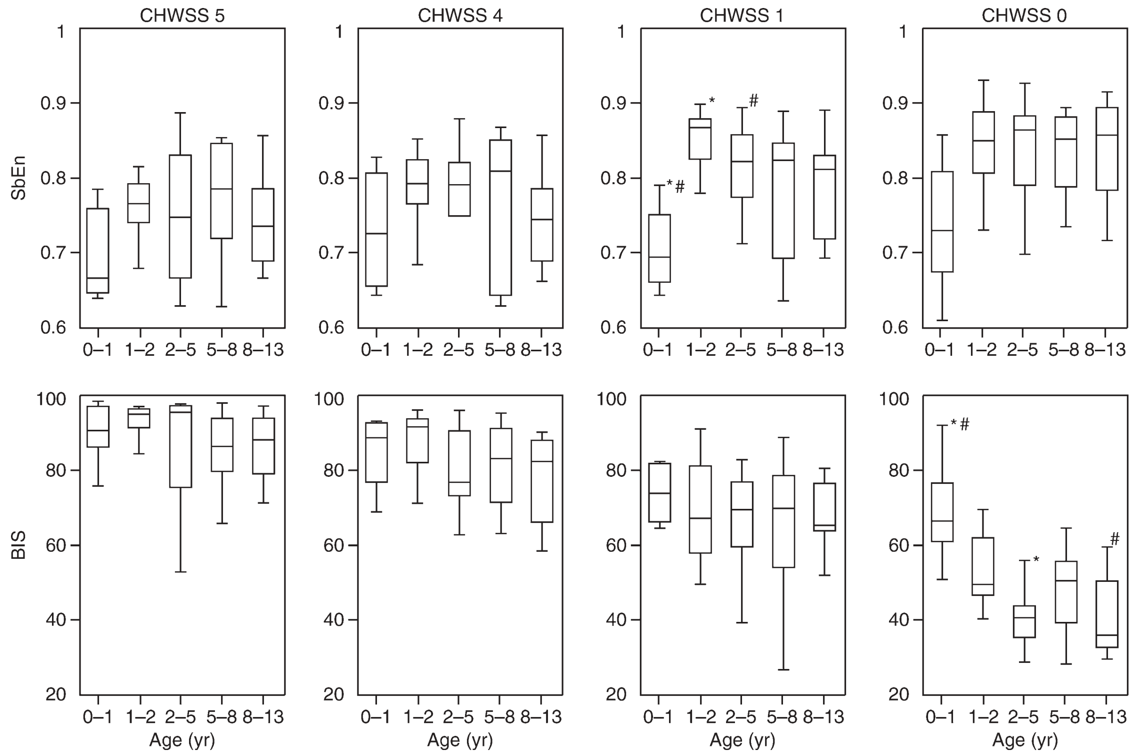

Fig 5 Box and whisker plot of symbolic entropy (SbEn) and BIS assessed during different CHWSS scores. CHWSS, Children's Hospital of Wisconsin Sedation Scale; box lines, the lower quartile, median, and upper quartile values; box whiskers, lines from each end of the box for the extent of the rest of the data. $^{*,\#}P<0.05$.

seven-level arousal scale by CHWSS. The quantal nature of the observational score may result in different values of the EEG variable for the same arousal level. As long as the inverse situation does not occur, that is the same value of the EEG variable for different levels of arousal, the EEG variable is a good predictor for the levels of arousal. This important constraint is considered by the Pk statistic, but not by correlation or other association statistics.[15]

The gradation of the observational score may influence the results of Pk analysis. Unfortunately, this is a common difficulty with all validated observational scales.[24] The higher this gradation the more accurate is the characterization of the functional relationship between observational score and processed EEG. In our analysis, the multilevel observational scale was determined by the sequence of possible stimuli of graded intensity that occur during the clinical course of surgical anaesthesia. Rapid changes in patient's level of arousal as mainly observed during induction or recovery from anaesthesia were assessed every 30 s by four levels of the observational scale (CHWSS of 1–4). The remaining three levels of the observational scale represented the awake/sedated state without stimulation (CHWSS of 5–6), or anaesthesia during intensive surgical stimuli (CHWSS of 0). This gradation of the observational scale was considered to be adequate for a reliable quantification of the degree of association between processed EEG and observational score.

The Pk analysis of each EEG variable was performed on pooled data pairs from all patients during the analysis period. Because of this analysis approach and the clinical course of anaesthesia, the amount of data pairs having a CHWSS of zero is greater than data pairs with a CHWSS different from zero. Therefore, one would expect an increased Pk value for an EEG variable, if all values of the EEG variable being part of data pairs with a CHWSS of zero would not occur in data pairs with a CHWSS different from zero. The amount of Pk bias produced by this imbalance of data pairs may be relevant in an individual Pk analysis, in which only the within-patient variability is considered, that is the same EEG value may occur for different levels of arousal only during different points in time in the same patient. However, the present pooled approach simultaneously takes into consideration both the within-patient and the between-patient variability, that is the same EEG value may indicate one level of arousal in one patient and a different one in another patient, and it may occur for different levels of arousal during different points in time. Therefore, the probability that the same values of processed EEG would only occur in pairs with a CHWSS of zero in all patients at all investigated time points is rather unlikely and so also the amount of Pk bias.

In conclusion, BIS may provide a similar measure of arousal during propofol anaesthesia in children older than 1 yr as it does in adults. As the Pk values of the selected high-frequency components of EEG, SEF95, and approximate entropy were less than 0.7, the use of these indices as measures of arousal in children requires caution.

In infants less than 12 months, low-frequency components of the EEG and SEF50 could be more useful for measuring arousal during surgical anaesthesia.

Supplementary data

A detailed description of the processing method and the estimated ECG variables is given in the Appendix at *British Journal of Anaesthesia* online.

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