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Reduced EEG montage has a high accuracy in the post cardiac arrest setting

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HIGHLIGHTS

- A reduced electrode montage may be used for post cardiac arrest EEG monitoring.
- Background patterns were almost perfectly assessed with a reduced montage.
- Discharge patterns were identified with high accuracy.

ABSTRACT

Objective: To study if comatose cardiac arrest patients can be assessed with a reduced number of EEG electrodes.
Methods: 110 routine EEGs from 67 consecutive patients, including both hypothermic and normothermic EEGs were retrospectively assessed by three blinded EEG-experts using two different electrode montages. A standard 19-electrode-montage was compared to the reduced version of the same EEGs, down-sampled to six electrodes (F3, T3, P3, F4, T4, P4). We used intra-rater and inter-observer statistics to assess the reliability of the reduced montage for background features and discharges.
Results: The reduced montage had almost perfect performance for background continuity (κ 0.80–0.88), including identification of highly malignant backgrounds (burst-suppression/suppression) (κ 0.85–0.94) and benign backgrounds (continuous/nearly continuous) (κ 0.85–0.91). We found substantial performance for identifying rhythmic/periodic discharges (κ 0.79–0.86). The reduced montage had high accuracy for assessment of both highly malignant (sensitivity 91–95%, specificity 94–99%) and benign (sensitivity 89–98%, specificity 91–96%) backgrounds, and periodic/rhythmic patterns (sensitivity 79–100%, specificity 89–99%), compared to the full montage. The inter-observer variability was not increased by the reduced montage.
Conclusion: Reduced EEG had high performance for classifying important background and discharge patterns in this post cardiac arrest cohort.
Significance: Our results support the use of reduced EEG-montage for monitoring comatose cardiac arrest patients.

1. Introduction

EEG is recommended and commonly used for prognostication of brain injury in comatose cardiac arrest (CA) patients in the intensive care unit (Friberg et al., 2015). EEG is used to detect electrographic seizures and assess the background activity as part of the multimodal neurological prognostication (Hawkes and Rabinstein, 2019; Sandroni et al., 2014).

Continuous EEG-monitoring (cEEG) has been advocated for early seizure detection and to follow the temporal evolution of the cortical recovery after CA (Herman et al., 2015), but is not always available due to lack of resources and neurophysiology assistance for setup and quality adjustments. A limited montage with fewer electrodes may enable bedside staff to apply and main-

Abbreviations: ACNS, American Clinical Neurophysiology Society; CA, cardiac arrest; cEEG, continuous EEG monitoring; IQR, interquartile range; κ, kappa; SIRPIDs, stimulus-induced rhythmic, periodic or ictal discharges.

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tain the recording at an early stage, without the need of a 24-hour in-house neurophysiology service (Friberg et al., 2013).

A reduced montage could be especially suitable after CA due to the often widespread anoxic brain damage and was found to provide valuable prognostic information (Dragancea et al., 2015; Westhall et al., 2018). Even a single-channel EEG was sufficient to show a high association between EEG background and outcome (Oh et al., 2015). However, only a few studies have evaluated a reduced montage in comparison to a full montage after CA and often restricted the assessment to a few predefined EEG patterns. One study detected no differences in prognostic information or inter-observer agreement with nine recording electrodes for background patterns and epileptiform activity (Tjepkema-Cloostermans et al., 2017). Another study on a small number of postanoxic patients found high accuracy for ictal patterns, but compared an eight-lead montage with a 12-lead montage (Vanherpe and Schrooten, 2017).

EEG interpretation is based on visual assessment and dependent on skills and experience, including definitions of the described EEG features. This was demonstrated in studies on the inter-observer variability of EEG assessment, reporting a wide range of kappa-values (κ) from slight to almost perfect agreement (Benarous et al., 2019; Grant et al., 2014). In 2013 the American Clinical Neurophysiology Society (ACNS) published an internationally accepted EEG classification for critically ill patients (Hirsch et al., 2013). Using this standardized EEG terminology, interpretation of full montage EEGs on post CA patients were reported to have substantial inter-observer agreement on background continuity (κ 0.76) and voltage (κ 0.65), but moderate agreement on presence of periodic or rhythmic patterns (κ 0.56) (Westhall et al., 2015). It is advocated that studies on prognostic performance should use standardized definitions (Callaway et al., 2015; Hawkes and Rabinstein, 2019; Kleinman et al., 2018).

The aim of this study was to evaluate the performance of a reduced montage with six recording electrodes compared to a full montage in a post arrest cohort, using assessments based on the ACNS classification (Hirsch et al., 2013).

2. Methods

2.1. Population and EEG recording

We included consecutive comatose adult post CA patients as part of the Target Temperature Management trial (Nielsen et al., 2013) (ClinicalTrials.gov NCT01020916) at three Swedish hospitals (Lund, Malmö and Helsingborg) between November 2010 and January 2013. All patients received targeted temperature management in accordance to the protocol (Nielsen et al., 2012). As part of a predefined EEG substudy, the instruction was to record one routine EEG of at least 20 minutes during the intervention period (hypothermia) and one routine EEG in patients still comatose after normothermia, representing important time-points for prognostication (Rossetti et al., 2017; Spalletti et al., 2016; Westhall et al., 2018). EEGs performed up to seven days after CA were included. EEG was recorded with Nicolet One EEG monitors (Care Fusion Inc, USA) with 19 surface electrodes placed according to the international 10–20 system, plus reference and ground electrode in the midline. The files were stored in a full montage and in a downsampled montage with six recording electrodes (F3, T3, P3, F4, T4, P4) according to Fig. 1.

2.2. EEG montage and review

We used two performance tests to validate EEG reviewing with the reduced montage. We studied if each EEG-expert classified the EEG patterns differently when reviewing the same EEG with the reduced montage as with full montage (intra-rater variability) and if the inter-observer variability increased using the reduced montage compared to the full montage.

Three senior EEG specialists (SB, EW, IR), blinded to all clinical information, independently reviewed the EEGs in random order with full montage (gold standard) and with reduced montage (Fig. 2). All EEG interpretation was performed in a bipolar montage (Fig. 1) with the possibility to adjust filter settings and sensitivity, and to change to a referential common average montage. Fig. 3 shows EEG examples of the two montages. Clinical notations in the EEG files were removed, except for time points and type of reactivity testing. No video recording was available. Files for reactivity assessment were excluded if they contained less than two pain stimuli and two sound stimuli. Assessment was based on the ACNS terminology with pre-defined categories. After one to two months, the EEG specialists repeated the review of the full montage EEG files. The intra-rater data from two repeated full EEG reviews were used for comparison with the intra-rater data between reduced and full-montage EEG reviews.

The reviewers classified and completed a case report form containing the following items:

- Background continuity: continuous, nearly continuous, discontinuous, burst-suppression or suppression. If fluctuating background, the best background present for at least two minutes was reported.
- Background amplitude: <10 μV (suppressed), 10–<20 μV (low voltage), 20–<50 μV or $\geq$50 μV
- Presence or absence of reactivity; confident or not confident in the reactivity-assessment
- Presence of identical bursts and/or highly epileptiform bursts
- Presence of rhythmic delta activity
- Presence of periodic discharges or rhythmic polyspike-/spike-/sharp-and-waves
  - o Prevalence (rare < 1%, occasional 1–9%, frequent 10–49%, abundant 50–89%, continuous $\geq$ 90%)
  - o Localization (generalized, lateralized, bilateral independent or multifocal)
  - o Typical frequency and maximum frequency
- Presence of definitive seizure activity ($\geq$10 seconds of focal or generalized evolving discharges reaching >4 Hz or generalized polyspike-/spike-/sharp-and-waves $\geq$3 Hz)
- If no periodic or rhythmic patterns were present, the amount of sporadic epileptiform discharges were reported (none, occasional <1/minute, frequent $\geq$1/minute but <1/10 seconds, abundant $\geq$1/10 seconds)
- Presence of an epileptiform EEG (periodic discharges or rhythmic polyspike-/spike-/sharp-and-waves, highly epileptiform bursts, definitive seizures, status epilepticus or abundant sporadic epileptiform discharges $\geq$1/10 seconds)

2.3. Statistics

The intra-rater agreement was calculated for each reviewer and EEG feature, comparing the scoring for the reduced montage with the first full montage review (gold standard) (Fig. 2). Intra-rater agreement between the two assessments of the full montage EEGs was calculated as reference. To assess if the inter-observer variability of pattern classification increased with a reduced montage, inter-observer agreements were calculated for the first full montage EEG review (gold standard) as well as for the reduced montage EEG classification.

Linearly weighted kappa was used for rank-ordered variables. Dichotomized and categorical variables were assessed with Coheńs kappa for intra-rater agreement and Fleiss kappa for inter-observer

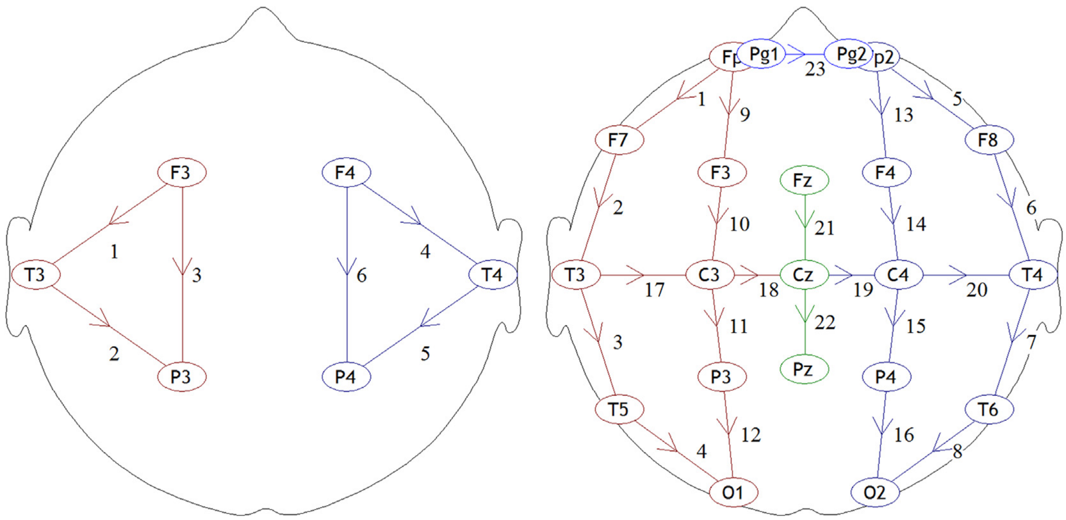

Fig. 1. Montages. Location of the six electrodes of the reduced montage and the 19 electrodes of the full montage. The reference electrode was placed in the midline between the Cz and Pz positions.

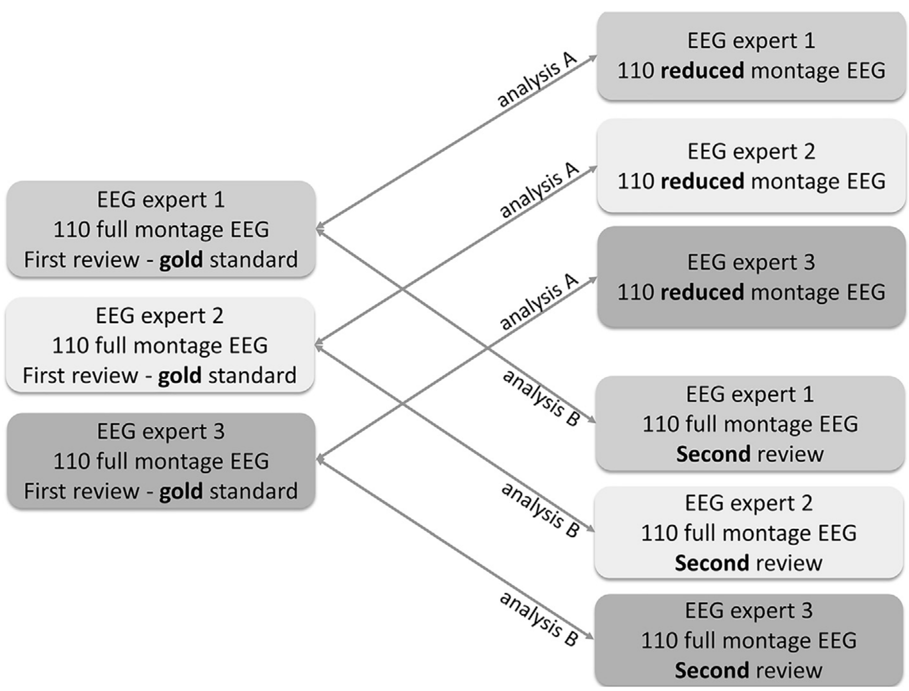

Fig. 2. Inter-method comparison by intra-rater agreement assessments. Each EEG-expert reviewed the 110 EEGs with full montage (gold standard) and with reduced montage, followed by a second review with the full montage. For assessment of the performance with the reduced montage, kappa-values (intra-rater agreement), sensitivity and specificity for each EEG-expert were calculated (analysis A). Corresponding agreement between repeated assessments of full montage EEGs were calculated for comparison (analysis B).

agreements. Sensitivity and specificity were evaluated for the reduced montage compared to the gold standard. Subclassification of specific parameters for rhythmic and periodic patterns were only analyzed for the subgroup, where all reviewers had chosen the pattern to be present. Intra-rater strength, sensitivity or specificity were not analyzed if a category was used in more than 90% of the assessments by any of the reviewers. The strength of kappa coefficients are presented as poor (≤0), slight (0.01–0.20), fair (0.21–0.40), moderate (0.41–0.60), substantial (0.61–0.80) or almost perfect (0.81–1.00) (Landis and Koch, 1977). Confidence intervals for percentages were calculated using Wilsońs method including continuity corrections.

2.4. Ethical approval

Ethical approval was received from Regional Ethical Review Board Lund, Sweden (protocol 2009/324, 2011/669).

3. Results

3.1. Included patients and EEG recordings

After exclusion of four EEGs due to excessive artefacts, 110 EEGs from 67 patients were included and analyzed. The EEG files had a

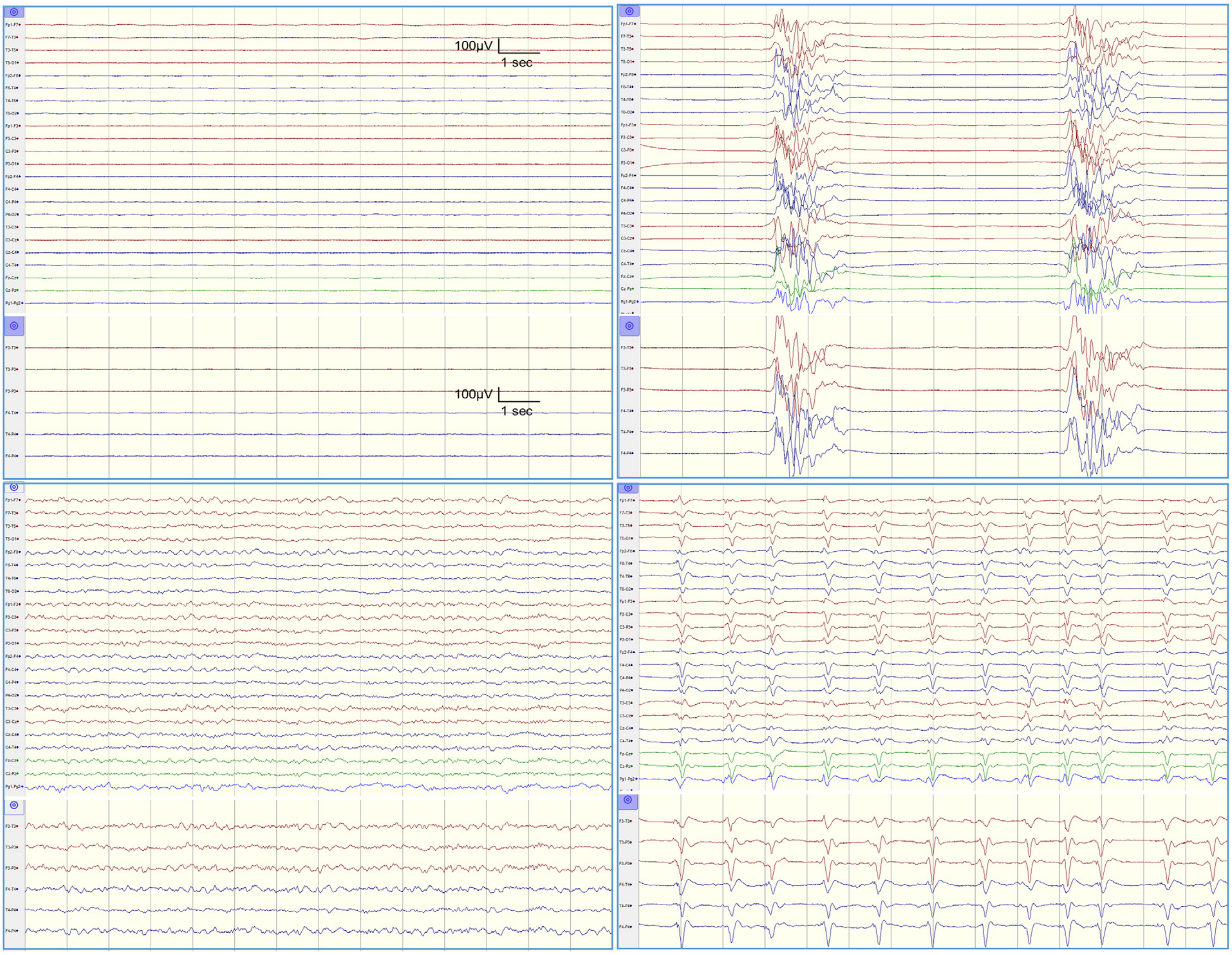

Fig. 3. EEG recordings with the two montages. Four examples of full montage and reduced montage from the same EEG section. Upper left shows a suppressed background, lower left a continuous background, upper right a burst-suppression pattern and lower right continuous periodic discharges on a suppressed background.

median duration of 21 minutes (IQR 20–26) and they were recorded at a median 46 hours (IQR 22–80) after CA.

3.2. Inter-method comparison using intra-rater agreement statistics

Table 1 shows the distribution of the different EEG patterns in the first full montage review from the three reviewers. Continuous normal-voltage background was the most commonly reported background pattern (30%). Intra-rater agreement for each reviewer and EEG feature comparing reduced montage EEGs with the full montage EEGs, is presented in Table 2. Intra-rater agreement for the two repeated interpretations of the full montage EEG files is presented as a reference. The background continuity assessed with reduced montage was found to have substantial to almost perfect strength of agreement (κ 0.80, 0.87, 0.88). Similarly, there was almost perfect agreement (κ 0.85, 0.93, 0.94) using reduced montage for the highly malignant (suppression or burst-suppression) background patterns and for the benign (continuous or nearly continuous) background patterns (κ 0.85, 0.86, 0.91). The sensitivities and specificities for these patterns were at least 89% with the reduced montage compared to the first full montage review. These intra-rater variability results, sensitivity and specificity data, were similar to the reference results of the repeated assessments of the full montage-EEGs (Table 2).

Reactivity-testing was performed and documented in 85% of the EEG files. Absent reactivity to stimuli was reported in 61%, including recordings with only stimulus-induced rhythmic, periodic or ictal discharges (SIRPIDs) (Table 1). There were substantial to almost perfect agreement for reactivity comparing the reduced and the full montage review (κ 0.75, 0.78, 0.85). The EEG-experts reported that they were not confident in their assessment of reactivity in 24% of the reduced montage EEGs and in 18% of the full montage EEGs.

Periodic discharges or rhythmic sharp-and-waves were found in 32% of the EEGs (Table 1). Of these patterns, 84% consisted of periodic discharges, 76% were generalized and 39% appeared continuously. The most typical frequency was 1.0 Hz. With the reduced montage periodic or rhythmic patterns were detected with a high sensitivity (79%, 87%, 100%) and specificity (89%, 97%, 99%), with substantial to almost perfect intra-rater kappa coefficients (κ 0.79, 0.80, 0.86) (Table 2). For comparison, repeated review of the same full-montage EEG resulted in sensitivity values between 97% and 100% and specificity of 94–99%. An epileptiform EEG was present in 33% of the full montage EEGs and was detected with high accuracy with the reduced montage (sensitivity 90%, 93%, 96%; specificity 89%, 97%, 97%).

3.3. Inter-method comparison using inter-observer agreement statistics

Disagreement among the EEG-experts did not increase with the reduced montage compared to the gold standard (Table 3). Similar

Table 1
Prevalence of EEG patterns. The total number of answers (n = 330) from three EEG-reviewers (110 EEGs /reviewer) in the first full montage EEG interpretation (gold standard) is presented. SIRPIDs, stimulus-induced rhythmic, periodic or ictal discharges.

Prevalence of EEG patterns, n = 330									
Background									
Continuity	Continuous 33%		Nearly continuous 14%		Discontinuous 11%		Burst-suppression 23%		Suppression 19%
	Continuous normal voltage 30%		Continuous low voltage 3%						
Bursts	Identical bursts 9%		Highly epileptiform bursts 6%						
Amplitude	<10 µV 19%		10–20 µV 15%		20–49 µV 52%		≥50 µV 13%		
Reactivity to sound or pain (n = 279)	Present 39%				Absent 60%		SIRPIDs only 1%		
Reactivity	Present and confident 30%		Present and not confident 9%		Absent and not confident 9%		Absent and confident 52%		
Discharges									
Rhythmic delta	Present 10%		Absent 90%						
Periodic/rhythmic patterns (excluding rhythmic delta)	Periodic discharges 27%		Rhythmic sharp waves 5%		Absent 68%				
Prevalence (n = 106)	Rare 5%		Occasional 11%		Frequent 24%		Abundant 22%		Continuous 39%
Typical frequency (Hz) (n = 106)	<0.5 5%	0.5 18%	1.0 38%	1.5 19%	2.0 9%	2.5 3%	3.0 2%	3.5 0%	≥4.0 7%
Maximal frequency (Hz) (n = 106)	<0.5 0%	0.5 8%	1.0 21%	1.5 22%	2.0 18%	2.5 7%	3.0 3%	3.5 2%	≥4.0 20%
Localization (n = 106)	Generalized 76%		Lateralized 9%		Bilateral independent 11%		Multifocal 3%		
Definitive seizures/status epilepticus	Present 3%		Absent 97%						
Epileptiform EEG	Present 33%		Absent 67%						

and substantial kappa values were seen for background continuity (reduced montage κ 0.75. 0.76, 0.78 vs. gold standard κ 0.74. 0.78, 0.80) and the presence of periodic or rhythmic patterns (reduced montage κ 0.80 vs. gold standard κ 0.72). The highly malignant background features (burst-suppression or suppression) had almost perfect kappa values (reduced montage κ 0.84 vs. gold standard κ 0.86). The agreement for reactivity was less good for both methods (reduced montage κ 0.59 vs. gold standard κ 0.68).

4. Discussion

Since postanoxic encephalopathy typically has widespread cortical distribution, a reduced number of electrodes may be adequate for prognostication based on generalized background patterns and generalized periodic discharges. In this study on a defined post-arrest cohort, a six electrode EEG-montage showed substantial to almost perfect performance regarding assessment of background activity and discharge patterns compared to the full-montage EEG.

Previous studies, comparing reduced EEG montage with a full montage in critically ill patients with mixed etiologies, have primarily focused on seizure detection (Karakis et al., 2010; Rubin et al., 2014) or on a few selected background patterns (Herta et al., 2017; Ma et al., 2018). Studies have showed considerable variation in the reliability of a reduced montage, which may be explained by a different selection of patients and EEG patterns, the number of categorization options and the experience of the EEG reviewers. Additionally, electrode distribution and length of the presented EEG samples may affect the results (Gururangan et al., 2018; Herta et al., 2017; Ma et al., 2018). Studies using electrodes restricted to the frontal or sub-hairline regions report lower sensitivity for detection of seizures compared to studies using a more even scalp coverage (Tanner et al., 2014; Young et al., 2009).

When studying EEG for prognostication after CA, it is important to adhere to standardized definitions and to validate the different methodological setups, for instance electrode-montages. In this study we used the standardized EEG terminology of the ACNS; a terminology which has had a major clinical impact and has been used in recent studies (Beuchat et al., 2018; Bongiovanni et al., 2020).

For CA patients, background continuity has been shown to have high prognostic ability and is commonly used for this purpose (Backman et al., 2018; Oh et al., 2015; Tjepkema-Cloostermans et al., 2015). With our reduced montage we found similar performance for the background assessment as for review with the full routine EEG montage. For CA patients, an early identification of patients with a potential for good recovery may aid in clinical decision-making. In our study, the reduced montage had high accuracy for a benign background, i.e. a continuous background. Additionally, it is important to collect information indicating a

Table 2
Inter-method comparison by intra-rater variability. Diagnostic performance with the reduced montage and the full-montage review (analysis A) presented as intra-rater variability. The first full montage interpretation compared to the second full montage interpretation for each reviewer (analysis B) is presented for comparison.

	Reduced montage versus full montage Analysis A according to Fig. 2			Repeated assessment of full montage Analysis B according to Fig. 2		
	Kappa (95% CI)	Sensitivity (95% CI)	Specificity (95% CI)	Kappa (95% CI)	Sensitivity (95% CI)	Specificity (95% CI)
Background						
Continuity*	0.80 (0.72–0.88)			0.73 (0.64–0.83)		
	0.87 (0.83–0.93)			0.89 (0.85–0.94)		
	0.88 (0.83–0.93)			0.91 (0.87–0.95)		
Amplitude*	0.65 (0.54–0.76)			0.73 (0.63–0.84)		
	0.69 (0.60–0.79)			0.77 (0.69–0.86)		
	0.77 (0.68–0.86)			0.80 (0.72–0.89)		
Suppressed/burst-suppression**	0.85 (0.75–0.95)	0.91 (0.77–0.97)	0.94 (0.84–0.98)	0.83 (0.72–0.94)	0.91 (0.77–0.97)	0.92 (0.82–0.97)
	0.93 (0.86–1.00)	0.94 (0.83–0.98)	0.98 (0.90–1.00)	0.95 (0.88–1.00)	0.98 (0.88–1.00)	0.97 (0.88–0.99)
	0.94 (0.88–1.00)	0.95 (0.83–0.99)	0.99 (0.91–1.00)	0.98 (0.94–1.00)	1.00 (0.90–1.00)	0.99 (0.91–1.00)
Continuous/nearly continuous**	0.86 (0.76–0.95)	0.89 (0.78–0.96)	0.96 (0.86–0.99)	0.75 (0.62–0.87)	0.86 (0.74–0.93)	0.89 (0.76–0.95)
	0.85 (0.75–0.95)	0.95 (0.83–0.99)	0.91 (0.81–0.96)	0.89 (0.80–0.97)	0.91 (0.77–0.97)	0.97 (0.89–0.99)
	0.91 (0.83–0.99)	0.98 (0.89–1.00)	0.93 (0.82–0.98)	0.89 (0.81–0.98)	0.91 (0.79–0.97)	0.98 (0.89–1.00)
Present reactivity**	0.78 (0.65–0.92)	0.79 (0.61–0.90)	0.97 (0.87–0.99)	0.79 (0.66–0.92)	0.85 (0.67–0.94)	0.93 (0.83–0.98)
n = 93	0.85 (0.74–0.95)	0.95 (0.80–0.99)	0.91 (0.80–0.97)	0.91 (0.83–1.00)	0.97 (0.84–1.00)	0.95 (0.84–0.99)
	0.75 (0.62–0.89)	0.79 (0.63–0.90)	0.94 (0.84–0.99)	0.84 (0.73–0.96)	0.87 (0.72–0.95)	0.96 (0.86–0.99)
Discharges						
Presence of periodic/rhythmic sharp wave patterns**	0.79 (0.66–0.92)	1.00 (0.83–1.00)	0.89 (0.80–0.95)	0.88 (0.78–0.98)	1.00 (0.83–1.00)	0.94 (0.86–0.98)
	0.86 (0.76–0.96)	0.87 (0.71–0.95)	0.97 (0.89–1.00)	0.96 (0.91–1.00)	0.97 (0.85–1.00)	0.99 (0.91–1.00)
	0.80 (0.68–0.92)	0.79 (0.64–0.89)	0.99 (0.91–1.00)	0.96 (0.91–1.00)	1.00 (0.90–1.00)	0.97 (0.89–0.99)
Maximal frequency*	0.71 (0.53–0.89)			0.70 (0.52–0.87)		
n = 25	0.74 (0.55–0.92)			0.81 (0.69–0.93)		
	0.87 (0.79–0.96)			0.82 (0.68–0.96)		
Typical frequency*	0.51 (0.26–0.77)			0.41 (0.14–0.69)		
n = 25	0.65 (0.44–0.87)			0.58 (0.30–0.86)		
	0.61 (0.33–0.89)			0.68 (0.44–0.92)		
Prevalence*	0.59 (0.36–0.83)			0.72 (0.53–0.92)		
n = 25	0.74 (0.57–0.90)			0.82 (0.63–1.00)		
	0.81 (0.66–0.96)			0.89 (0.77–1.00)		
Epileptiform EEG**	0.78 (0.65–0.91)	0.96 (0.80–1.00)	0.89 (0.80–0.95)	0.82 (0.70–0.94)	0.96 (0.80–1.00)	0.91 (0.83–0.96)
	0.88 (0.79–0.97)	0.90 (0.75–0.97)	0.97 (0.89–1.00)	0.94 (0.87–1.00)	0.97 (0.85–1.00)	0.97 (0.89–1.00)
	0.90 (0.82–0.98)	0.93 (0.80–0.98)	0.97 (0.89–0.99)	0.94 (0.88–1.00)	1.00 (0.90–1.00)	0.96 (0.87–0.99)

* Weighted kappa is used for rank-ordered variables.
** Cohens kappa is used for categorical variables (yes/no). The kappa values, sensitivity and specificity are presented for each reviewer.

poor prognosis, i.e. suppression or burst-suppression after the initial period. The reduced montage had high sensitivity and specificity for these patterns as well and also good inter-observer agreement.

Presence of epileptiform activity is a poor prognostic sign, but with less prognostic performance compared to background continuity (Westhall et al., 2018). There are no large studies evaluating the sensitivity for a reduced montage to detect discharge patterns in adult CA patients. In our study we found substantial to almost perfect intra-rater agreement and high sensitivity of the reduced montage for identifying rhythmic or periodic discharge patterns. However, the results were slightly lower than a repeated review of a full montage EEG. This could be due to that some focal low amplitude periodic discharges have been missed with the reduced montage. On the other hand, the importance of detecting and treating these patterns is still unknown and controversial in the post CA setting. A randomized prospective trial on the treatment of seizures is ongoing (Ruijter et al., 2014).

Our reduced montage also had a high performance for reactivity. However, the EEG-experts reported in a substantial portion of the reactivity assessments, that they were not confident with any of the montages. Due to high inter-observer variability (Westhall et al., 2015) and often lack of standardization, it is suggested that reactivity as a prognostic feature could benefit from standardization and possibly quantification (Admiraal et al., 2017, 2018, Duez et al., 2018).

A limitation of our study is that it includes only experienced EEG-experts from a single site with long experience of reduced montages. Although a prior study showed that the ACNS terminology can be used by unexperienced reviewers (Gaspard et al., 2014), other studies emphasize the importance of experience in EEG interpretation (Benarous et al., 2019). Before changing current clinical routines, there is a need for prospective studies with less experienced EEG-reviewers of a reduced montage. Further, our results cannot be extrapolated from the global postanoxic setting to other patients groups.

We included consecutive CA patients which resulted in a limited number of less frequent patterns, such as identical bursts and definitive evolving seizure activity. The accuracy of the reduced montage for identifying these patterns cannot be addressed in this study. Further studies focusing on these patterns are needed.

cEEG is recommended for unconscious patients after CA (Herman et al., 2015). However, full montage monitoring is resource demanding (Crepeau et al., 2014), necessitating continuous support by an EEG department. Prospective studies on the value of cEEG compared to routine EEG after CA is lacking. In this study we show a high agreement for the EEG classification between full and reduced montage. The reduced montage evaluated in the present study has been used for many years for simplified cEEG at several intensive care units in the southern regions of Sweden. It is applied by bedside nurses who received a brief train-

Table 3
Inter-method comparison by inter-observer agreement for reduced montage EEG review and full montage EEG review.

Inter-observer agreement, n = 110 EEG	Reduced montage Kappa (95% CI)	Full montage (gold standard) Kappa (95% CI)
Background		
Continuity*	0.78 (0.71–0.85)	0.80 (0.74–0.87)
	0.76 (0.68–0.84)	0.78 (0.70–0.86)
	0.75 (0.67–0.83)	0.74 (0.66–0.82)
Amplitude*	0.57 (0.45–0.69)	0.66 (0.55–0.78)
	0.64 (0.53–0.76)	0.66 (0.55–0.78)
	0.51 (0.40–0.62)	0.56 (0.45–0.69)
Suppressed/burst-suppression**	0.84 (0.74–0.96)	0.86 (0.76–0.97)
Continuous/nearly continuous**	0.77 (0.66–0.89)	0.77 (0.66–0.88)
Present reactivity** n = 93	0.59 (0.48–0.70)	0.68 (0.56–0.79)
Discharges		
Presence of periodic/rhythmic sharp wave patterns**	0.80 (0.70–0.91)	0.72 (0.61–0.83)
Epileptiform EEG**	0.73 (0.63–0.84)	0.74 (0.63–0.85)

* Weighted kappa for rank-ordered variables for inter-observer agreement are presented for every two reviewers.
** Fleiss overall inter-observer kappa values are presented for the categorical variables (yes/no).

ing, enabling the EEG monitoring to be started earlier and maintained with good quality around the clock (Friberg et al., 2013). A reduced montage could thereby facilitate the implementation of cEEG at lower costs. A full montage routine EEG may be added when clinically indicated.

For this study we used routine EEGs which were applied by certified EEG technologists and then down-sampled to a reduced montage EEG. A limitation is that we cannot exclude that these EEG samples were of higher technical quality than those applied and maintained by bedside personnel for the continuous monitoring. Additionally the possible effect on prognostication and outcome for the individual patient has not been studied. Further studies to evaluate the impact of the reduced montage on cEEG monitoring on outcome prediction are warranted.

5. Conclusion

A reduced EEG montage can be used with high performance for assessments of background activity and rhythmic or periodic patterns in comatose patients after CA. Further studies including reviewers from multiple centers and with less experience is warranted to validate our results and to evaluate the impact of reduced montage EEG monitoring on outcome prediction using multiple prognostic tools.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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