Methodology

The practice of rescaling scalp-recorded event-related potentials

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Received 9 November 2004; accepted 21 November 2005
Available online 24 January 2006

Abstract

In a recent article the principles of and the recommended practices for rescaling scalp-recorded electrophysiological data were submitted to a comprehensive review [Urbach, T.P., Kutas, M., 2002. The intractability of scaling scalp distributions to infer neuroelectric sources. Psychophysiology 39, 791–808]. The authors argued, on both conceptual and pragmatic grounds, that the practice of rescaling be discontinued when the motivation for rescaling was to infer that at least partially non-overlapping brain regions were engaged in two different experimental conditions. This article is a response to that proposal, and the key observations are that: (1) there remain sound theoretical reasons for rescaling when the motivation for rescaling is to infer that not entirely the same cognitive processing is engaged in two conditions and (2) at least for certain classes of experimental design the pragmatic concerns raised by Urbach and Kutas are not sufficient to warrant recommending that rescaling be discontinued.

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Keywords: Event-related potentials; Voltage maps; Statistical analysis; Scaling methods

1. Introduction

One approach to analysing scalp-recorded electrophysiological signals is to submit the data to an analysis of variance (ANOVA) with factors that include condition and location. This approach permits an assessment of how differences between electrical activity vary according to the experimental manipulations (the conditions), as well as the locations from which data were acquired. The presence of a reliable interaction involving these two factors provides evidence consistent with the view that brain activity is qualitatively different across the conditions of interest.

It is possible, however, to obtain interactions between condition and location that come about solely because activity in the same set of generators is greater in one condition than the other, and this arises because the additive ANOVA model is incompatible with the multiplicative relationship between neural activity and scalp-recorded activity (Hansen and Hillyard, 1980; McCarthy and Wood, 1985). In an influential paper, McCarthy and Wood (1985) discussed procedures for treating scalp-recorded electrophysiological data in order to remove this ambiguity, one solution being to rescale the data in order to remove overall amplitude differences across conditions while retaining differences (if any) between the shapes of the distributions.

In a recent article, Urbach and Kutas (2002) provided a rigorous and timely analysis of the principles and practices of rescaling time-locked electrophysiological data recorded from the scalp. They emphasised important limitations on the inferences that can be made when there is evidence that the shapes of the distributions of scalp-recorded brain activity – hence the spatial configurations of the underlying generators – are not the same across conditions. In addition, they demonstrated that one common procedure for rescaling electrophysiological data discussed by McCarthy and Wood (1985) – the vector length method – is problematic in that there are circumstances under which rescaling can provide evidence consistent with the view that there are shape differences between a pair of scalp distributions when in fact no such differences exist. On the basis of these observations, Urbach and Kutas proposed that the practice of rescaling electrophysiological data in order to make inferences about the spatial configuration of underlying generators should be discontinued.

This is an important issue, and one that has repercussions for the majority of researchers who employ scalp-recordings of neural activity in order to make inferences about neural and functional processes. It is equally relevant to researchers who
work with patients and/or with control populations, and applies to electroencephalography as well as to magnetoencephalography. The following discussion is motivated by the conclusions of Urbach and Kutas, and by recent references to their work, in which widely different stances have been adopted (for details see Section 5). To anticipate, the arguments put forward here are that: (1) while the conceptual arguments of Urbach and Kutas are sound there remain circumstances in which it is desirable to analyse rescaled data and (2) for at least one class of experimental design the practical problems with rescaling that Urbach and Kutas observe are not sufficient in and of themselves to recommend discontinuing the practice of rescaling using the vector length method.

2. Theoretical considerations

Assume that statistical evidence for reliable differences between the shapes of the scalp distributions in two experimental conditions has been obtained via an analysis of rescaled data. That is, the analysis of the scaled magnitudes has revealed an interaction between condition and electrode site. What this finding rules out is the possibility that any interactions between condition and electrode location that were obtained when the data were analysed prior to rescaling (the measured distributions) are due to the fact that there is a simple multiplicative relationship between the measured distributions in the two conditions, whereby the two can be equated simply by multiplying the values in one condition by a given value (McCarthy and Wood, 1985).

Using the terminology of Urbach and Kutas, the fact that a condition by electrode interaction remains after rescaling licenses – at least in principle – the conclusion that the spatial configurations of the generators responsible for the distributions in the two conditions are not equivalent. They observe, however, that in order for this conclusion to hold, the definition of changes in spatial configuration can encompass changes not only in the number and/or location of the generators that are responsible for differently shaped scalp distributions, but can also be restricted to changes in the relative levels of activity in the same set of generators, and/or changes in the polarity of one or more of the generators.

Thus one important possibility is that scalp distributions with different shapes arise because different brain regions are engaged in a pair of conditions. An equally important alternative, however, is that the same regions are engaged in two conditions, but the relative activity within those regions varies with condition. Urbach and Kutas note that this alternative account is acknowledged by some authors but not by others (Alain et al., 1999; Picton et al., 2000). They emphasise, furthermore, that the existence of the latter possibility means that rescaling should not be pursued if the intention is to make inferences about the engagement of at least partially non-overlapping brain regions in a pair of conditions.

This observation is an important one to re-emphasise, although questions remain. For example, how should electrophysiological evidence for differences between the shapes of distributions be interpreted when there is converging evidence from neuropsychology or functional magnetic resonance imaging (fMRI) suggesting that different brain regions are indeed engaged in the conditions of interest? Of greater importance for present purposes is a second point, which is that the same functional inference can be made irrespective of the reasons for obtaining evidence consistent with the view that the spatial configurations of the underlying generators are not equivalent. That is, the functional claim that distinct cognitive processes were engaged in two conditions is agnostic with respect to whether different brain regions were responsible, or whether the relative levels of activity in the same set of brain regions varied across conditions. In order to make the functional inference that qualitatively different cognitive processes are engaged, the fact that the spatial configurations – as defined by Urbach and Kutas – are different is sufficient (Donaldson et al., 2003), although some other caveats in respect of this remain (Rugg and Coles, 1995).

If this argument is accepted, then the question turns to whether there are procedures available that can provide reliable evidence concerning the presence or absence of differences between the spatial configurations of generators that are active in a pair of conditions. Urbach and Kutas note that analysing rescaled data can, at least in principle, rule out the possibility that the shapes of two scalp distributions are the same, by demonstrating that there is not a simple multiplicative relationship between the two distributions. In the second part of their article, however, they argue that one recommended rescaling procedure – the vector length method (Picton et al., 2000; Ruchkin et al., 1999) – is not reliable because of practical problems that can arise when using this method to rescale scalp-recorded electrophysiological data.

3. Practical considerations

The vector length method for rescaling was described initially by McCarthy and Wood (1985) and recommended subsequently by Picton et al. (2000) in a comprehensive set of guidelines on the acquisition, analysis and presentation of electrophysiological data. Briefly, the vector length method involves computing the square root of the sum of squares of the amplitude values from an array of electrode sites (the vector length). The rescaled value at each electrode location is then calculated by dividing the amplitude value at that location by the vector length, yielding a set of scaled magnitudes. In the recommended implementation (the across-participant computation), the vector length for a data set consisting of \( n \) participants is calculated on the mean amplitude values for each electrode site across the participants. The outcome of this computation is then used as the divisor for the data from each electrode location for each participant in order to yield a set of scaled magnitudes. If there is a simple multiplicative relationship between the amplitudes of the scalp-recorded data in two conditions, and no differences between the shapes of the distributions, then ANOVA with factors of condition and location computed over the vector-length rescaled data will not reveal an interaction involving location.
The work of Urbach and Kutas illustrates how two factors can increase the likelihood that incorrect inferences about differences between the shapes of two distributions will be made. These factors are task-related activity which changes during the post-stimulus epoch but which is not stimulus-locked, and noise in scalp-recorded data. They illustrated via simulations and worked examples that both of these factors can lead to an increase in the likelihood of Type I errors, and these are discussed in turn below.

### 3.1. Task-related activity and baseline correction

Urbach and Kutas identified baseline correction as one factor that is problematic when analysing rescaled data using the vector length method. While the examples they provide illustrate how activity that may have been ongoing during the baseline period and which continues but is not constant during the post-stimulus period may be problematic for the vector length method, this is not strictly speaking a problem due to baseline correction per se. When ERPs are recorded time-locked to an event of interest, for example the onset of a stimulus, baseline correction is employed routinely, and for good reason, in order to exert some control over the influence of pre-stimulus electrical activity on post-stimulus activity that is elicited by the stimulus. The typical procedure for baseline correction is to compute, for each electrode location, the mean level of pre-stimulus activity over a relatively narrow time window (∼100–200 ms) and subtract this value from all data points in the recording epoch (including the pre-stimulus baseline values). This procedure will remove amplitude differences between conditions that are evident pre-stimulus and which remain constant throughout the post-stimulus epoch of interest. It will not remove the influence of task-related activity that is not time-locked to stimulus presentation, but which changes during the post-stimulus epoch. It is this second type of activity that is problematic for rescaling using the vector length method. This will be referred to hereafter as task-related activity, in order to distinguish it from neural activity that is time-locked to the events of interest, and from baseline activity that continues unchanged during the post-stimulus epoch. In keeping with the approach taken by Urbach and Kutas, the discussion here is restricted to circumstances under which, within a given experiment, task-related activity is the same across experimental conditions but can vary according to electrode location.

The examples given by Urbach and Kutas illustrate that, except in the case where task-related amplitudes remain unchanged throughout the post-stimulus epoch, task-related activity can result in changes to the values of the scaled magnitudes such that statistical evidence for changes in spatial configurations will arise when in fact there are no such changes. The reasons why this may come about are described again briefly here with a view to illustrating an important caveat to the conclusions drawn by Urbach and Kutas.

Fig. 1 shows notional electrophysiological data recorded from three electrode locations. The format of the figure borrows heavily from Fig. 6 in the article of Urbach and Kutas, the numerical examples in this figure are similar to those in that article, but some column headings have been changed in order to emphasise that problems for vector scaling come about because of what is described here as task-related activity. In particular, column 1 denotes task-related activity for any given time period in the post-stimulus epoch, while column 2 denotes stimulus-related activity in the same epoch. Column 3, the measured distribution, is the sum of the values in columns 1 and 2. This can be assumed to be the data that are actually acquired in an experimental session. The figure demonstrates the influence that variations in task-related activity can have on data before and after vector scaling. In each of the three examples in Fig. 1 (see column 2), there is no shape difference between the two conditions: for each electrode location the stimulus-related amplitudes in condition 2 (C2: filled circles) are twice those in condition 1 (C1: unfilled circles).

Consider Row A in Fig. 1. Under these circumstances the application of the vector scaling procedure to the data results in equivalent scaled magnitudes because no values have been added to or subtracted from the post-stimulus amplitudes. This is illustrated in column 4 of Row A, where the estimates overlap perfectly. Column 7 shows the subtraction scores obtained by subtracting the scaled magnitudes computed for condition 1 (VS1) from those for condition 2 (VS2).

In Rows B and C of Fig. 1, the task-related amplitudes shown are non-zero, and this leads to differences between the actual stimulus related amplitudes (column 2) and the measured distributions (column 3). For Rows B and C, because the vector scaling procedure operates on the actual values at each electrode location (see Urbach and Kutas, for elaboration), adding or subtracting values to or from the mean amplitudes in each condition can result in differences between the scaled magnitudes across a pair of conditions, as columns 4 and 7 illustrate.

This influence of task-related activity is less problematic for analyses on unrescaled data, as the magnitudes of the amplitude differences between the conditions remain constant before and after this addition, but only of course in the circumstance where task-related activity in the post-stimulus epoch is equivalent across the conditions of interest. These observations, moreover, are critical for highlighting an important limitation with respect to the conclusions that can be drawn from the work due to Urbach and Kutas, namely that concerns about task-related activity are reduced considerably when vector scaling is computed over difference scores rather than over measured distributions obtained in single conditions: column 5 of Fig. 1 shows the outcomes of subtracting stimulus-related amplitudes for condition 1 from those for condition 2, while column 6 shows the outcomes of the equivalent subtractions completed for the measured distributions before vector scaling. These outcomes are invariant for the three cases depicted in Rows A through C.

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1 For formal accounts that support these observations, see Glaser and Ruchkin (1976).
This description in terms of the data shown in Fig. 1 is sufficient in and of itself to support the claim that vector scaling difference scores is a means of avoiding the distortions that might arise when rescaling some measured distributions: the fundamental observation here is that because differences between conditions at different electrode sites are numerically identical before and after the addition of a constant value to each condition, then applying the vector scaling procedure to those differences is less subject to the distortions that can occur when vector scaling is applied to single conditions. Whether task-related activity is typically of sufficient magnitude to be a serious concern when rescaling is applied to the data from single conditions remains an open question, because precisely how baseline-related activity changes during the post-stimulus epoch is difficult to assess. What the foregoing observations indicate, however, is that any potential problems can be largely circumvented by rescaling difference scores.

There are also several observations that follow from the fact that when vector scaled data based on difference scores is contrasted the analysis is less subject to concerns over task-related activity. For example, in the case of experiments containing four conditions (A–D), then contrasts of the rescaled data for subtraction pairings such as A–B versus C–D are not subject to these concerns. Consider, furthermore, the contrast between two sets of difference scores where one condition serves as a common subtractor. That is, the experiment contains
three conditions (A–C) and the contrast is between two subtractions, the A–C and the B–C pairings. This circumstance is depicted in Fig. 2, where it can be seen that under these circumstances the vector scaled difference scores are not subject to concerns arising from the presence of non-zero task-related values.

Column 1 of Fig. 2 mirrors to a large extent the same column in Fig. 1, depicting task-related post-stimulus amplitudes. The principal departure across figures is the use of 3 sets of potentials in Fig. 2, as can be seen in columns 1 and 2. As in Fig. 1, there is no shape difference between the C1 and C2 (column 2), and the figure illustrates that for each of the three sets of task-related values the scaled magnitudes of the two subtractions (C1 – C3, C2 – C3) are not prone to distortion in the same way as the conditions in Fig. 1 are when measured distributions from single conditions rather than difference scores were the units submitted to vector scaling. In order to avoid cluttering the figure, the numerical amplitude values for C1 and C2 are not shown in columns 2 and 3 of Fig. 2, but the values are identical to those shown in those columns in Fig. 1 for these two conditions.

Column 4 of Fig. 2 shows the difference scores obtained by subtracting the stimulus-related amplitudes (column 2) for condition 3 from conditions 1 and 2, respectively. Column 5

![Fig. 2. Amplitude measures, between-condition effects (difference scores) and scaled magnitudes for three arbitrary electrode locations. Columns 1 and 2 show the task-related values (B1–B3) and stimulus-related amplitudes (C1–C3), respectively. Task-related values vary in Rows A–C as for Fig. 1 and as in that figure the stimulus-related distributions are equal in each example (column 2, Rows A–C). Column 3 shows the measured distributions obtained by summing columns 1 and 2. Columns 4–7 show between condition effects. Column 4 shows the difference scores obtained by subtracting the stimulus-related amplitudes for condition 3 from conditions 1 and 2, respectively. Column 5 shows the outcome of the equivalent subtractions on the measured distributions (M1–M3). Column 6 shows the distributions of the measured effect (taken from column 5) while column 7 shows the (absence of) differences between the rescaled between-condition values. All other aspects of the figure are as for Fig. 1, with the exception of the use of diamonds in column 6 to distinguish the between-condition effects prior to vector scaling from the rescaled values and the differences between the rescaled values (column 7); µV: microvolts, s.m.: scaled magnitudes.](image-url)
shows the outcome of the equivalent subtractions on the measured distributions, the values for which are shown in column 3. The outcomes of these subtractions are invariant and equal across the three different task-related conditions. Columns 6 and 7, furthermore, illustrate that in each case the scaled magnitudes derived from the stimulus-related amplitudes and the measured distributions are identical. Thus, unlike the case for Rows B and C in Fig. 1, when vector scaling is computed over difference scores the addition or subtraction of constant values across conditions does not necessarily have a differential influence pre- and post-normalisation.

3.2. Noise in scalp-recorded electrophysiological data

In a series of examples and simulations Urbach and Kutas also demonstrated that in some instances data rescaled via the vector length method is vulnerable to false positives due to noise in the data. They showed that apparent differences between identically shaped patterns of scalp-recorded activity can come about because of the influence of noise on the computation of vector length. They showed that increasing noise tends to increase vector length, and since vector length determines the divisor for the unscaled amplitudes (as described above), this can lead to underestimation (‘flattening’) of the scaled magnitudes, which can in turn lead to an increased likelihood of a Type I error.

That the addition of noise can influence the likelihood of Type I error is unsurprising, and for data rescaled using the vector length method the underlying reason for this is equivalent to the earlier observations for the influence of baseline-related activity in the post-stimulus epoch. When noise is added there is no longer a simple multiplicative relationship between the shapes of two distributions, since what is being added to each condition is effectively a constant (which in this case may or may not be equivalent across conditions). Thus the baseline-related activity and noise issues discussed by Urbach and Kutas have a common root.¹

Some other observations of the data presented by Urbach and Kutas are also important here, however. First, in the simulations they presented the smallest increases in the likelihood of false positives occurred in the case where vector scaling was completed across participants. This is the recommended approach to vector scaling (McCarthy and Wood, 1985; Urbach and Kutas, 2002). Second, in so far as difference scores are considered to be comparable to a zero baseline condition, then when the data submitted to analysis comprise difference scores these are the conditions under which changes in noise levels are the least influential (see the ‘zero baseline’ condition in Fig. 10c of Urbach and Kutas, 2002). Neither of these observations means that noise is not a potential problem for the analysis of rescaled data, but they do emphasise that for certain classes of design the concerns are of less severity than for others. In this regard, the comments by Urbach and Kutas in their article in this issue are relevant, and point to the importance of inspecting closely difference wave data in the same way as Urbach and Kutas (2002) treated ERP data from single conditions.

4. Summary

Urbach and Kutas highlighted again an important conceptual issue, which is that the engagement of at least partially non-overlapping generators across a pair of conditions cannot be inferred on the basis of the survival of a reliable interaction between condition and electrode location following rescaling. This observation holds following application of any method for rescaling scalp-recorded electrophysiological data. Their data show that two factors – the influence of certain classes of activity in the post-stimulus epoch, and the fact that electrophysiological data can contain variable amounts of noise – have repercussions for the scaled magnitudes that are obtained using the vector length method of rescaling.

The initial conceptual observation that they re-emphasise is not open to dispute, but is a bar to rescaling only if the motivation for rescaling is to infer that at least partially non-overlapping generators are responsible for differences between the shapes of distributions. When the motivation for rescaling is to infer the engagement of functionally distinct processes, then this inference can in principle be made because different generators were engaged across conditions or because the relative levels of activity in the same generators were not equivalent (see Section 2 for comments).

It is also the case that concerns over the influence of task-related activity in the post-stimulus epoch can be ameliorated considerably by rescaling difference scores (see Section 3.1). This observation is of course of limited utility if experimental designs do not typically take a form where such contrasts are possible, but this is certainly not the case, and the approach described here is on that has been employed in a number of published studies. Analyses of the MMN (Naatanen, 1982; Naatanen et al., 1978), or indeed any modulation that is defined over the subtraction, fall within this class of designs. The literatures on ERP repetition effects (Rugg and Doyle, 1994) and ERP old/new effects (Friedman and Johnson, 2000; Rugg and Allan, 2000), moreover, contain many such designs, as well as examples of the employment of A–B versus C–D and A–C versus B–C contrasts on rescaled amplitudes. In addition, for A–B and C–D contrasts the pairings may come from separate conditions, experiments and/or populations, thereby providing considerable scope for the use of designs that avoid the problems that task-related activity can cause for analysing vector scaled ERPs. It is also worth noting that for analyses on data prior to rescaling, the use of subtraction scores when the critical contrasts come from data collected from different populations, or blocks in which task requirements differ, is a means of minimising contamination of post-stimulus activity with task-related activity that may differ across groups or blocks. These observations are not intended to imply that it is good practice to design experiments in order to enable such contrasts. The intention is primarily to illustrate that, for a non-trivial class of experimental designs, concerns about an increase in false positive rates because of problems related to ongoing task-related activity may not be applicable.

The second pragmatic concern regarding vector scaling relates to the negative influences of noise on the likelihood of
Type I errors. Urbach and Kutas demonstrated increases in the rate of false positives as a function of noise level. For vector scaling across participants, and on difference waves, however, these increases are modest at best, which raises the question regarding how the impact of noise on rescaled data of this form should be addressed. For circumstances under which the motivation for rescaling is to make functional inferences, the concerns over noise might be regarded as secondary given their relatively modest influence, since in order to infer that functionally distinct processes are engaged it is necessary to demonstrate that there are differences between the spatial configurations of generators in two conditions (using the broad definition of changes in spatial configurations outlined by Urbach and Kutas and repeated above). From this perspective, the concerns regarding the impact of noise reduce to being an appropriate note of caution and a reminder of the importance of replication and close inspection of the unrescaled data, an approach that has been advocated elsewhere recently (Dien and Santuzzi, 2005).

5. Concluding remarks

The paper due to Urbach and Kutas has attracted at least 17 citations in the short time since it was published. The authors of these papers have taken a variety of different stances with respect to the recommendations of Urbach and Kutas, and in the majority of cases the relevant comments have been restricted to a few lines (for exceptions, see Dien and Santuzzi, 2005; Dien et al., 2004). In some of these papers there were no reports of analyses of rescaled data and the references to the work of Urbach and Kutas dealt primarily with their comments concerning what can and cannot be inferred when there are differences between the shapes of distributions of electrical activity over the scalp (Coulson et al., 2005; Mathalon et al., 2003).

In the majority of papers in which Urbach and Kutas have been cited, their work has been referred to – either directly or indirectly – in relation to the practice of rescaling. Some have noted that the concerns of Urbach and Kutas do not apply in their case, either because of inspection of baseline variation in their own data (Herzmann et al., 2004), or because of the use of an alternative means for rescaling and/or analysis of subtraction scores (Dzulkifli et al., 2004; Henson et al., 2004; Hornberger et al., 2004). Others have simply noted the work but not the concerns of Urbach and Kutas (Schubo et al., 2004), whereas others have noted the concerns raised by Urbach and Kutas without raising objections and have analysed and interpreted rescaled data using the vector length method on difference scores (Duarte et al., 2004) or on data from individual conditions (Kaan and Swaab, 2003; Lueschow et al., 2004). Still others have either followed the recommendations of Urbach and Kutas (Proverbio et al., 2004; Trillenberg et al., 2004; Widmann et al., 2004), noted that the recommendations of Urbach and Kutas support circumspection when evidence for relatively subtle differences between the shape of distributions is obtained (Jost et al., 2004b; but see Jost et al., 2004a), or employed the work of Urbach and Kutas as justification for an approach whereby analyses of rescaled data from individual conditions are reported alongside analyses of dipole source solutions for the scalp-recorded ERPs acquired in different conditions (Potts, 2004).

The heterogeneous responses to the work of Urbach and Kutas emphasise the importance of further discussion and clarification concerning when and how scalp-recorded electrophysiological data should be rescaled (see Urbach, this issue). In combination, the arguments and observations made in this article delineate conditions under which there are good reasons motivating rescaling, and a non-trivial class of experimental designs for which concerns over task-related activity are small. When these criteria are met, then it seems reasonable to take the view that rescaling using the vector length method is at present an appropriate means of analysing scalp-recorded electrophysiological data.

It is to be hoped that the work of Urbach and Kutas (2002) will continue to stimulate research into the important issue of rescaling, the factors that influence the reliability of rescaling procedures, and also alternative methods of rescaling that might be less prone to the practical concerns that they have emphasised. In this regard, furthermore, it is certainly worth re-emphasising McCarthy and Wood’s observation that the use of ad hoc computational approaches for inferring differences between scalp distributions is necessitated by the fact that it is difficult to derive accurate models of neural generators on the basis of scalp-recorded activity (McCarthy and Wood, 1985).

There are, however, several recent developments that are relevant to this issue. These include the increased spatial resolution at the scalp afforded by the widespread availability of multi-electrode recording systems, recent applications of variants on principal components analysis as a means of reducing electrophysiological data (Makeig et al., 2004), the correspondence between certain frequency modulations in the electrical record and the BOLD signal (Logothetis et al., 2001), and advances in the ways in which source solutions can be modelled as well as constrained by anatomical and other data sources (Phillips et al., 2005, 2002). In combination, these research themes illustrate the continuing promise of source localisation as the long-term solution to the challenge of determining whether differences between scalp distributions are due to different configurations of neural generators. At the

\[2\] McCarthy and Wood (1985) also discussed a second rescaling computation – the max–min method – which normalises on the basis of the range of data points. In this method, the scaled value at a given site is computed by subtracting the minimum value across all electrode sites from the actual value at the site, and dividing this outcome by the amplitude differences between the maximum and minimum values across all sites. Thus for any given site, \( x \) following rescaling, \( 0 \leq x \leq 1 \). Since this method of rescaling is based on the difference between the maximum and minimum values taken from a given array of electrodes it is immune to the problem of non-zero baselines that are constant across conditions. This is because the range remains unchanged under these circumstances, as can be seen in column 3 of Fig. 1. Thus the problem for the vector length approach for rescaling single conditions does not arise for the range normalisation method. There are, however, some circumstances under which range normalisation is prone to Type II errors (Haig et al., 1997).
present time, however, it is important that this work continues alongside investigation and discussion of the principles and practice of rescaling scalp-recorded electrophysiological data.

References


