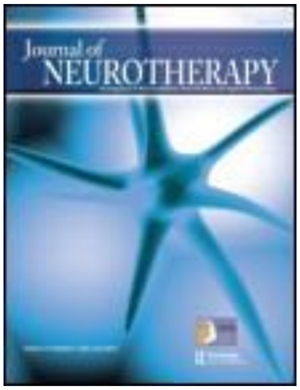

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Effectiveness of a Mini Live sLORETA Projection Technique for Screening EEGs for Power Asymmetries

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EFFECTIVENESS OF A MINI LIVE sLORETA PROJECTION TECHNIQUE FOR SCREENING EEGS FOR POWER ASYMMETRIES

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This report describes results obtained when a localization technique (sLORETA) is used with less than the full amount of scalp data normally required. It is concluded that it is possible to use partial surface data in reconstructing brain activity using sLORETA, under certain conditions. In particular, when a prominent frontal asymmetry was evident, it was possible to reliably detect the asymmetry, using only four frontal channels. This approach has potential value when working clinically, as it indicates that useful frontal asymmetry data can be obtained by combining 4-channels of frontal EEG with the sLORETA technique.

INTRODUCTION

This report examines the potential validity and usefulness of the concept of completing a partial reconstruction of brain activity using standardized Low Resolution Electromagnetic Tomography (sLORETA) in which a subset of the full 19-channel array is used. sLORETA was described by Pascual-Marqui (2002) and typically requires a minimum of 19 surface channels in order to achieve valid localization data for every voxel. Fundamentally, sLORETA is an estimation-based procedure that produces a statistical estimate for each voxel based upon the surface field. The statistic that is computed is the likelihood that a voxel is participating in the observed surface field. We were interested in learning whether this, as an estimation procedure, has possible value when not all of the intended channels are included in the estimation process. Hypothetically, when fewer than the intended channels are used in the estimation, the result will be expected to deviate from the proper comprehensive solution.

METHOD

In this study, we produced 10 samples of EEG data (five participants, each with an eyes-closed [EC] and an eyes-open [EO] acquisition), and created the sLORETA images for them using each of the following standardized methods: (a) full 19-channel reconstruction, (b) a reconstruction using 10 of the channels, (c) a reconstruction using six of the channels, and (d) a reconstruction using four of the channels (Table 1). The channels used were prescribed by the procedure detailed next.

Using the playback function of BrainMaster's BrainAvatar, we highlighted a few seconds of the EEG and displayed the desired frequency band. Using the same settings (portion of EEG and frequency band), one auto-paletted image was captured for each reconstruction (19, 10, six, and four electrodes). Therefore, four images were captured for each setting ($n = 25$) making a total of 100 images. Within the 25 settings, there were 14 that were EO and 11 that were EC. A focus on the frontal lobe occurred in 13 of the 25, leaving 12 posterior asymmetries for study. Altogether, the 25 settings included eight

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TABLE 1. Sample Locations for sLORETA Reconstructions

Frontal		Posterior	
19 channels	All 19 channels	19 channels	All 19 channels
10 channels	Fp1/Fp2	10 channels	O1/O2
	F7/F8		T5/T6
	F3/F4		P3/P4
	T3/T4		C3/C4
	C3/C4		T3/T4
6 channels	Fp1/Fp2	6 channels	O1/O2
	F7/F8		T5/T6
	F3/F4		P3/P4
4 channels	Fp1/Fp2	4 channels	O1/O2
	F7/F8		T5/T6

frontal EO, five frontal EC, six posterior EO, and six posterior EC.

For this analysis, we focused on one parameter, power asymmetry, as revealed by visual inspection of the sLORETA raw power images. We presented these images to naïve participants ($N = 8$), who were asked to score each image with regard to the lateralization of the image. The decision method was identical for all images. That is, the only decision to be made was which side of the image had more power (left or right) as indicated by a predominance of red color. All images were autoscaled to optimize the rendering of asymmetric power. The scores were compared across subjects and for each of the image sets. It did not matter, nor was it explained to the participants, that there was any difference in this aspect. They were instructed simply to identify and write down which side (left or right) had the greater power (amount of red). One benefit of using an approach based upon visual identification of asymmetries is that each individual serves as his or her own control. There is no need for a normative reference when the decision criteria are based solely on the presence of a visible imbalance between the hemispheres or across a hemisphere.

RESULTS

In viewing 19-channel asymmetries between hemispheres, blind raters had a discrepancy of 4%. In other words, out of 800 images (eight raters each viewing and rating a total of 100 images), only 32 of those images were marked as displaying more power (more red) on a different side than the others had rated. A 1.6% discrepancy suggests that frontal lobe asymmetry was easier to judge than posterior asymmetry, which had a 2.4% discrepancy. Coincidentally, the EO condition proved to have the most consistency between raters with 1.5% disagreement versus the EC condition which had a 2.5% disagreement rate between raters. More specifically, the EO condition had a 0.4% discrepancy in the front and 1.1% discrepancy in the back/posterior, compared to the EC condition that had a 1.25% discrepancy in both the frontal and posterior lobes.

When there is an asymmetry present within 19 channels, the 4-channel mLLP reliably reflects that asymmetry 83.5% of the time, according to blind raters. Similarly, the 6-channel mLLP reflected the 19-channel images 82% of the time, whereas the 10-channel reliably reflected the 19-channel images 87% of the time. Four-channel mLLP was not observed to introduce inaccurate lateralization information when the 19-channel images showed no clear asymmetry. Therefore, the likelihood of false positives is negligible when no asymmetries exist. In other words, 4-channel mLLP was not seen to provide spurious detections when there was nothing to identify.

Comparing the 4-channel, 6-channel, and 10-channel reconstructions with the 19-channel mLLP suggests that the 10-channel reconstruction provides the most accurate results with only two of the 25 images showing the opposite asymmetry as the 19-channel image and two additional images that do not show 100% agreement regarding which hemisphere has the greater power. In all, 174 of the 200 rated 10-channel images had the same hemispheric asymmetry as the corresponding 19-channel image. Only three of 25 images in the 10-channel reconstruction disagreed with what the 19-channel image displayed as the correct asymmetry. Surprisingly, the 6-channel had the lowest accuracy of producing a similar image depicting asymmetry as the 19-channel. Thirty-six of the 200 scored images in the 6-channel reconstruction were incongruous with the majority of raters. In 100% agreement, the raters marked three of the 25 images as having the opposite asymmetry as the 19-channel image, whereas three additional images were more difficult to determine which side appeared to have more power. Thus, six of 25, or 24%, of the 6-channel images produced activation that appeared to represent the opposite of what the 19-channel image depicted. Furthermore, the EC condition produced the majority of the discrepancy (five of eight images) within the 6-channel mLLP. In the 6-channel reconstruction, the raters had a difficult time distinguishing which hemisphere appeared to have greater power, resulting in 18% of the images being rated differently than the majority of raters.

Similarly, the 4-channel reconstruction yielded three images of the 25 that were different 100% of the time than what was seen in the 19-channel reconstruction, with an additional two images upon which raters did not agree. For example, in Image 17, three believed the left hemisphere displayed greater power, whereas five believed the right displayed more power.

The 4-channel reconstruction depicted the same asymmetry 100% of the time for those records in which an obvious left or right asymmetry existed in the full 19-channel sLORETA image, or those in which red is clearly greater on one side ($n = 14$; see Figure 1 for an example). On the other hand, the 6-channel reconstruction produced equal asymmetry in six of the 14 (43%) obviously sided asymmetries, whereas the 10-channel reconstruction had 11 of 14 images (79%) that depicted obvious and similar results to the 19-channel reconstruction. Therefore, the 4-channel reconstruction is the most useful when a dominant asymmetry exists; however, on average, a 10-channel reconstruction provides the most accurate depiction of the 19-channel mLLP when taking into account less defined asymmetries. Continuing with a more obscured asymmetry, the 6-channel reconstruction proved to be the least useful with an occurrence similar to that of an obvious asymmetry in the 19-channel mLLP. In addition, because obvious asymmetries are rarely missed, the likelihood of a false negative (missed abnormality) is low, when the region of interest is reflected in the chosen sites. If, for example, prefrontal alpha asymmetry (Baehr, Rosenfeld, & Baehr, 2001; Davidson, 1998; Kerson, Sherman, & Kozlowski, 2009) is of primary interest, then an mLLP based upon the prescribed locations of F7, Fp1, Fp2, and F8 will have a high likelihood of properly representing that asymmetry. It is possible to achieve this detection capability for any frequency band, and this study confirms these observations for delta, theta, alpha, low beta, beta, and gamma. The possibility of detecting brain asymmetries using an mLLP may be found useful in neurofeedback treatment recommendations for mood and anxiety disorders (Davidson & Begley, 2012; Hammond & Baehr, 2008), along with cognitive

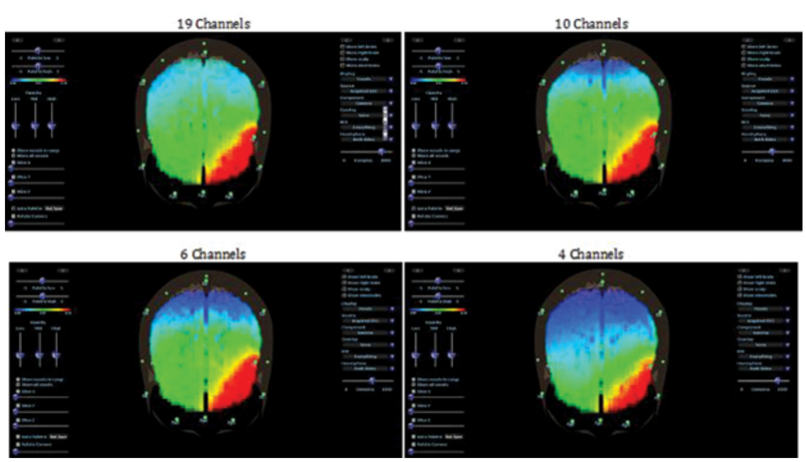

FIGURE 1. Example of a pronounced frontal asymmetry. (Color figure available online.)

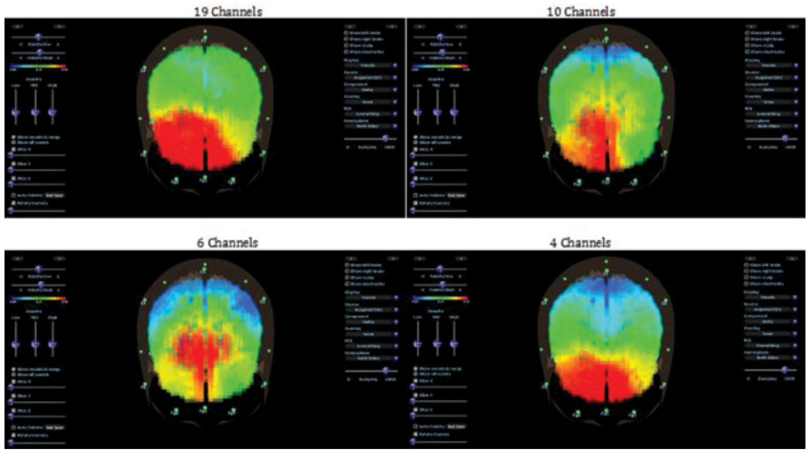

FIGURE 2. Example of a moderate frontal asymmetry. (Color figure available online.)

performance related concerns (Fritson, Wadkins, Gerdes, & Hof, 2007).

In those images where the asymmetry is not as obvious ($n = 11$; see Figure 2 for an example), there is less accuracy within all channel reconstructions. Specifically, the 10-channel reconstruction had the same asymmetry 73% of the time, whereas the 6- and 4-channel reconstruction depicted the same asymmetry as the 19-channel image 36% and 45% of the time, respectively. It can be said that the less obvious asymmetries, or those that were spread across hemispheres, would be more difficult to detect because prescribed locations were used for mLLP imaging, and those prescribed locations may have missed the exact locations of the asymmetry. For example, the prescribed posterior 4-channel reconstruction includes O1, O2, T5, and T6. Therefore, if there is a posterior beta asymmetry that is not also evident in the occipital regions, then the mLLP will most likely miss the asymmetry because the reconstruction is focused on a different location than the existing asymmetry. Unfortunately, it is unknown if or how the asymmetry will appear in the mLLP since the reconstruction is focused on an adjacent region to where the asymmetry actually exists and is displayed in the 19-channel mLLP. Consequently, when multiple asymmetries exist, the complex pattern that is evident on the 19-channel mLLP image may be distorted or even reversed (occurring completely in eight of the 75 images encompassing 10-, 6-, and 4-channel reconstructions) in an mLLP image if the electrodes that are chosen are distant from the dominant sites. This is analogous to the ''looking for one's keys under the streetlight'' analogy.

DISCUSSION

This study demonstrates the clinical utility of an approach that might, at first, be considered less than promising. mLLP violates certain assumptions of sLORETA implementation, which limits its potential usefulness. It is possible to identify the circumstances under which these violations produce clinically significant limitations or inaccuracies. By examining sample data and conducting trial interpretations according to defined criteria, we were able to assess the potential value of mLLP images, in comparison with conventional 19-channel mLLP images. By using prescribed locations for mLLP imaging and applying well-defined decision criteria, we were able to demonstrate that 4-channel sLORETA projections have value as a clinical decision-making tool. However, the images thus produced were generally not interpretable as spatial portions of the whole 19-channel mLLP image. Although their appearance may or may not be a distortion of the appearance of the full head solution, they can be used to ascertain whether the total sLORETA would exhibit clear asymmetries with adequate reliability.

Although it does violate some key principles of sampling and multivariate estimation, the concept of mLLP is faithful to other principles in that sLORETA is fundamentally an estimation process that computes likelihoods (''F-scores'') and expresses them for individual voxels. Therefore, as an estimation process, not unlike a multiple least-squares estimation, it can be computed for any subset of the representative data and still provide an estimate. Whether that estimate is useful can be determined by examining representative data. The sLORETA process consists of multiplying the scalp field vector (19 channels) by a transform matrix containing 6,239 rows and 19 columns. The matrix provides multiplying coefficients for each channel as it is reflected in its probability for each voxel. Therefore, the sLORETA, being a linear combination of channels, is a form of smoothing that combines each channel's data with its neighbors so as to estimate underlying sources. It can thus be viewed as a generic smoothing approach in which applying the matrix to a subset of channels produces a lower-order, but nonetheless valid estimate.

When estimating a function or data set, a single point provides a first-order estimate. This reflects an attempt to ascertain the expected, or mean, value for all points. When two points are used, a second-order estimate is possible, reflecting both the value and the variation and direction of a vector. A third-order estimate can produce an ''inflection'' in the data, and a fourth-order estimate can reflect possible ''inflections'' or contours in the data. The sLORETA procedure produces a 19th order estimate because 19 points are used for each frequency band. In this context, the mLLP is seen simply as a fourth-order estimate so that it can provide some estimate of the size of the sample, as well as some of the contour features, such that a fourth-order estimate can produce.

Consequently, sLORETA produces a statistical estimate for each voxel, which is the likelihood that the voxel is participating in the observed surface field. If there is a single dominant dipole, then the voxels associated with that dipole region are guaranteed assignment by sLORETA to the maximum probability. With mLLP, a subset of channels is chosen for projection, whereas the others are set to zero. This limits the possible solution space but does not invalidate it as an estimator. If a subset of channels is chosen that suitably spans a pronounced asymmetry, then the mLLP image is guaranteed to reflect the spatial distribution in a locally valid manner.

After reconstructing a variety of 19-channel EEG acquisitions into 10-, 6-, and 4-channel reconstructions, eight participants, who were unaware of the purpose of this study, rated which side, left or right, appeared to have the most power (greater amount of red). In doing so, raters agreed 100% of the time on 86 of the 100 images. Three of the eight participants responded differently in eight of those 14 images. For example, seven participants agreed upon which hemisphere had more power in five of the images, leaving only one divergent response. Consequently, three images produced a tie, where four marked the left and four marked the right as having more power.

Although it is true that an mLLP image cannot be relied upon as an image per se, its potential value as a screening method cannot be dismissed carelessly. Generally, when viewing an LLP image, it will not be possible to interpret that image as a ''slice'' or ''portion'' of the entire 19-channel solution. Local maxima, minima, and contours will dominate any global patterns if the local region is not typical. Therefore, the value of an mLLP as a screening tool will take the form of ''what can be concluded if X is seen'' and ''if Y is the case, what can be expected in an mLLP in certain cases'' and ''how reliable is mLLP when used for decision making?'' Both false positives (unnecessary red flags) and false negatives (missed abnormalities) can be considered in this analysis.

The use of a subset of channels to estimate a pattern can be likened to detecting any pattern, say the order of cards in a deck, based upon a subset of the data. If it is known, for example, that a deck is organized in a particular fashion, such as ascending order, or by suits, then a smaller sample of cards will suffice to determine the pattern of the deck. Similarly, if certain facts are known or assumed with regard to the surface EEG and its sLORETA solution, then a subset of the full 19-channel computation can be evaluated for its ability to correctly identify the overall pattern.

CONCLUSION

Participants were able, with minimal instruction, to learn to identify and record the side of greater power when presented with mLLP images produced with 4-, 6-, and 10-channel reconstructions of the 19-channel mLLP. Blind raters completely agreed upon 96% of the image classifications. Moreover, out of the 75 images produced by the 10-, 6-, and 4-channel reconstruction, 14 of them (where at least half of the participants believed the power was greater on the opposite side of what was found in the 19-channel mLLP) depicted the asymmetry on the opposite side. This equates to an 81% overall accuracy rate when reconstructing a 19-channel EEG acquisition using mLLP. In narrowing the 19-channel images, using only those that have an apparent and dominant asymmetry ($n = 14$), the 10-channel reconstruction was 79% accurate, and the 4-channel reconstruction was 100% accurate in predicting what the 19-channel reconstruction depicted. Unfortunately, the 6-channel reconstruction was only correct 43% of the time. With regard to the 19-channel mLLP that had varying and less obvious asymmetry, the 10-channel reconstruction was 73% accurate and the 4-channel reconstruction was 45% accurate. Typically, the 6-channel reconstruction was correct only 35% of the time.

Consequently, the 10-channel reconstruction is the most useful tool in making accurate conclusions regarding asymmetry based upon the 19-channel reconstruction when the asymmetry is less obvious. However, the 4-channel reconstruction also provides useful information when addressing the asymmetry of power in the left and right hemispheres when one hemisphere is clearly dominant. Furthermore, using a 10-channel mLLP or a 4-channel mLLP was found to be more accurate than the 6-channel mLLP in all conditions. Also, frontal mLLPs and those that were EO acquisitions were found to be easier to classify and had more overall agreement between the raters, possibly due to more clearly designated asymmetries. This demonstrates that a 10- and 4-channel mLLP has validity as a screening tool and that it provides useful information related to lateralization when reflected in the form of asymmetry of power displayed in the sLORETA solution. Further research must be completed for an overall conclusion regarding reliability and validity with the use of 4-, 6-, or 10-channel reconstructions based upon a 19-channel mLLP, with a focus on whether the image becomes distorted or reversed depending upon the number of channels and the placement of electrodes within the reconstruction.

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