Prospects for mobile, high-definition brain imaging: EEG spectral modulations during 3-D reaching

S. MAKEIG[1], J. ONTON[1], T. J. SEJNOWSKI[1,2], H. POIZNER[1]

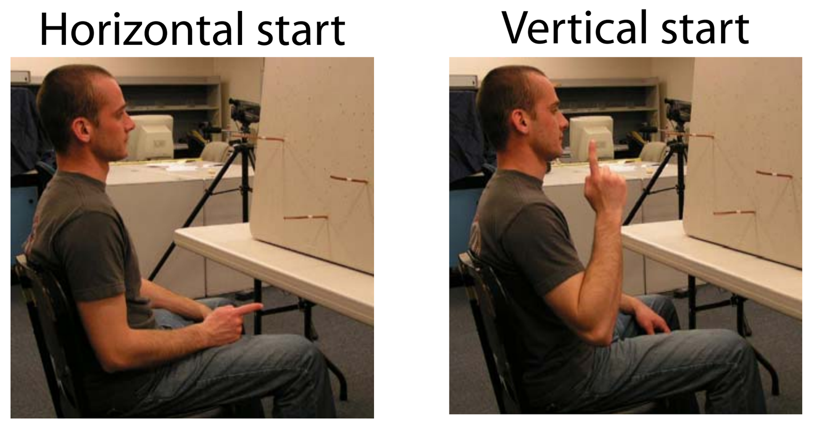
[1] Institute for Neural Computation, Univ Calif, San Diego, CA

[2] Computational Neurobiology Laboratory, Howard Hughes Medical Institute, The Salk Institute, CA

QUESTIONS

1) What EEG dynamics are associated with reaching for targets in 3-D space?
2) What stimulus or other factors determine the spectral dynamics accompanying each reach event?

REACHING TASK



- Subject sits in the dart facing a pegboard
- Three LEDs protrude from board (L|M|R)
- One LED is lit at a time (in random order)
- Subject reaches to touch LED with stiff right finger, then returns to rest
- Two resting conditions: hand in lap ('horizontal'), hand upright ('vertical')
- Touches rarely successful w/o visual guidance

METHODS

EEG data were collected from 4 normal, healthy male subjects using 254 scalp electrodes. Independent EEG activities were identified using independent component analysis (ICA) on artifact-free EEG that was high-pass filtered above 1 Hz. ICA activations for non-artifact independent components (ICs) were epoched around each LED onset signalling the beginning of each reach trial. Each trial was differentiated by the starting hand position (horizontal or vertical -- see picture) and by the target reach direction (left, center or right). Concurrently acquired movement information from infrared sensors on the finger, wrist elbow and shoulder were converted into

1) movement onset, 2) maximum acceleration, 3) maximum velocity, 4) maximum deceleration, and 5) movement offset.

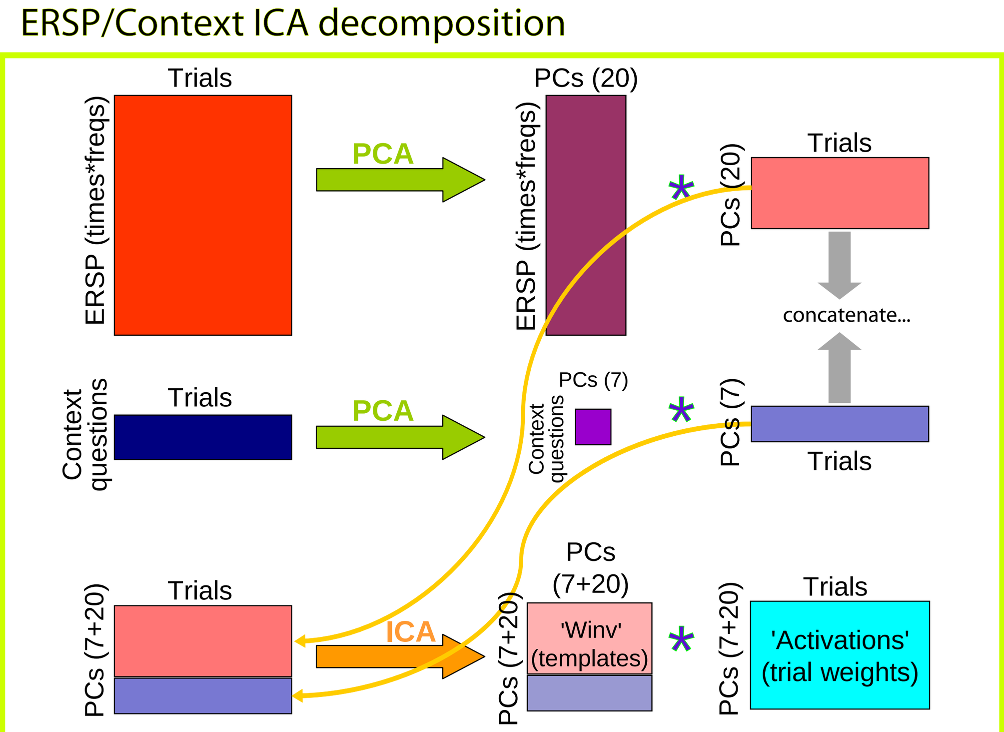
These trial markers were merged with the EEG data so that each trial could be analyzed with regard to these 5 behavioral events. Single trials were transformed into time/frequency spectrograms or event-related spectral perturbations (ERSPs). The resulting imageswere interpolated such that all movement events would align across trials. Dividing the trials, the ERSPs were either averaged to show large differences between conditions, or submitted to a single-trial analysis designed to extract common ERSP and context features across trials. Here, single-trial ERSPs were collected across trials to form a (ERSP x trials) matrix (see diagram), reduced by principal component analysis (PCA) to the first 20 PCs (first row). Each trial was described by a set of yes/no *context*

questions:

1) Left reach? 2) Center reach? 3) Right reach?
4) Same as last reach?
5) Was the last reach right of the current one?
6) Was the last reach left of the current one?
7) Vertical start position? 8) Horizontal start position?
9) Will the current target be successfully touched?
10) Was the last target successfully touched?

Answers to these questions were accumulated into a single matrix of size (10 questions x trials) and reduced to the largest 7 PCs by PCA (second row). PC matrices for ERSPs and contexts were concatentated to form a (20+7 x trials matrix) (bottom row). This matrix was then decomposed using ICA to find maximally independent trial types, as evidencedby *both* ERSP and context features. Results of this decomposition gave, for each subject, an inverse weight matrix ('winv') which provided the activity templates found by ICA, and an 'activations' matrix that contained trial weightings for each 'winv' template.

ERSP/Context ICA decomposition



1) Context-dependent factor templates

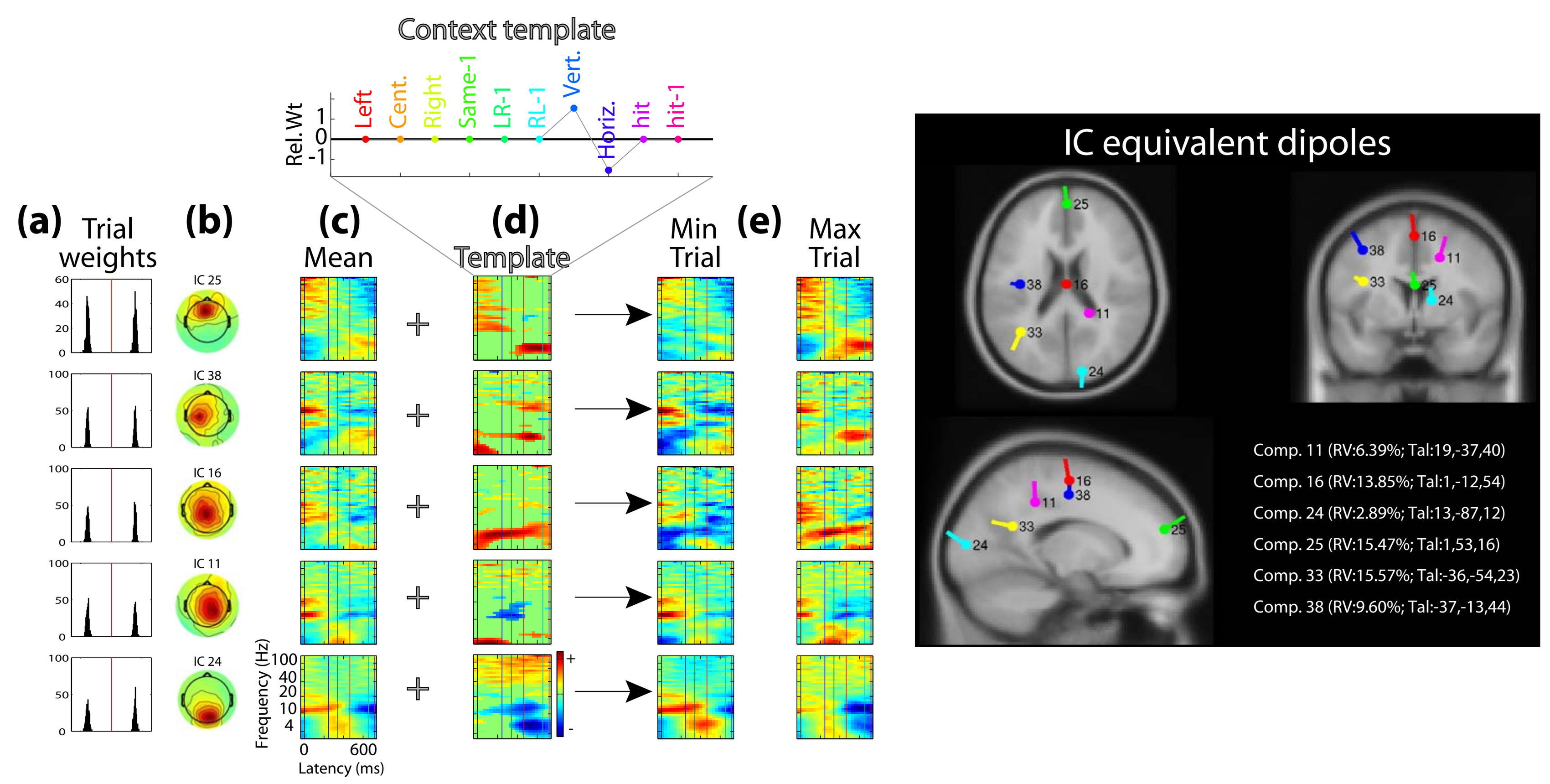


Figure 1. Even in simple experimental paradigms, trial activities are modulated by a number of independent context factors. In these data, changes in EEG spectral (log) power associated with a reach to a target are modulated by starting pose, reach directions, and/or previous-trial events -- all are aspects of the trial '*context*'. For five ICs from one subject, (column **b**) one context template (above) favors reaches starting from the vertical (versus the horizontal pose). Deviations from the mean ERSPs (column **c**) associated with this factor are chosen in column **d** (masked for significance - see Methods). These templates, multiplied by the trial weights (see histograms (**a**) on left) form the back-projected effects of this template in single trials. The back-projections of the min-weighted and max-weighted trials (with mean ERSP added back) are shown in the rightmost ERSP columns (**e**). Note the association of ERSP and template features to the critical points of the reach (vertical lines, see Methods).

3) Repeated reaches to center target

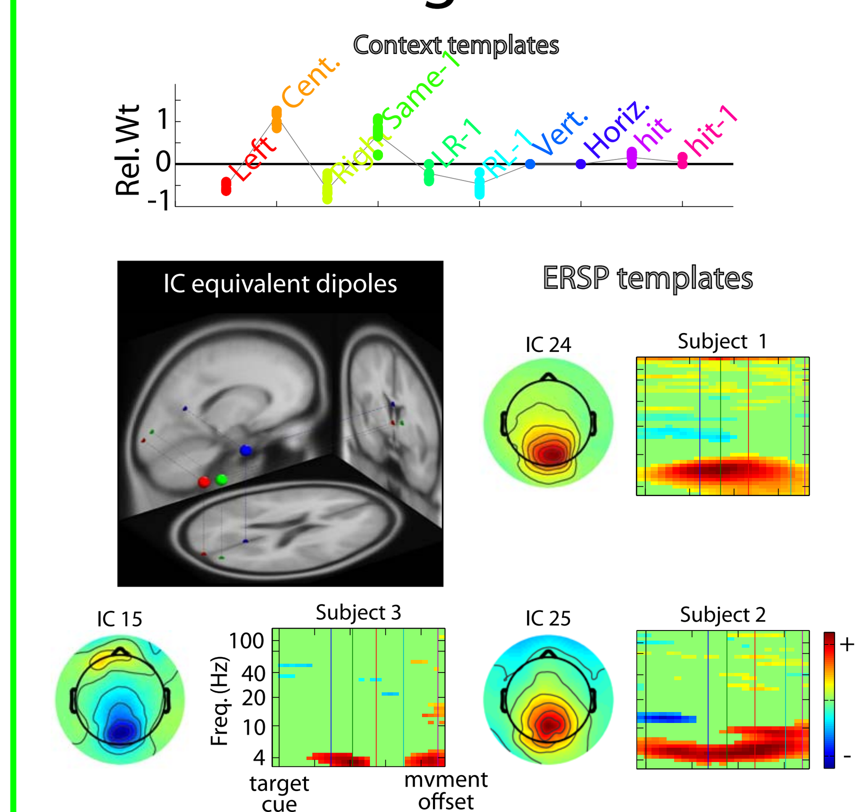


Figure 3. Context templates, clustered across subjects, may reveal consistent EEG modulation patterns. Here, in ICs from 3 of the 4 subjects, 4-8 Hz theta power was increased during reaches directed toward the center target following a reach to the same location in the previous trial.

4) Pre-hit or miss?

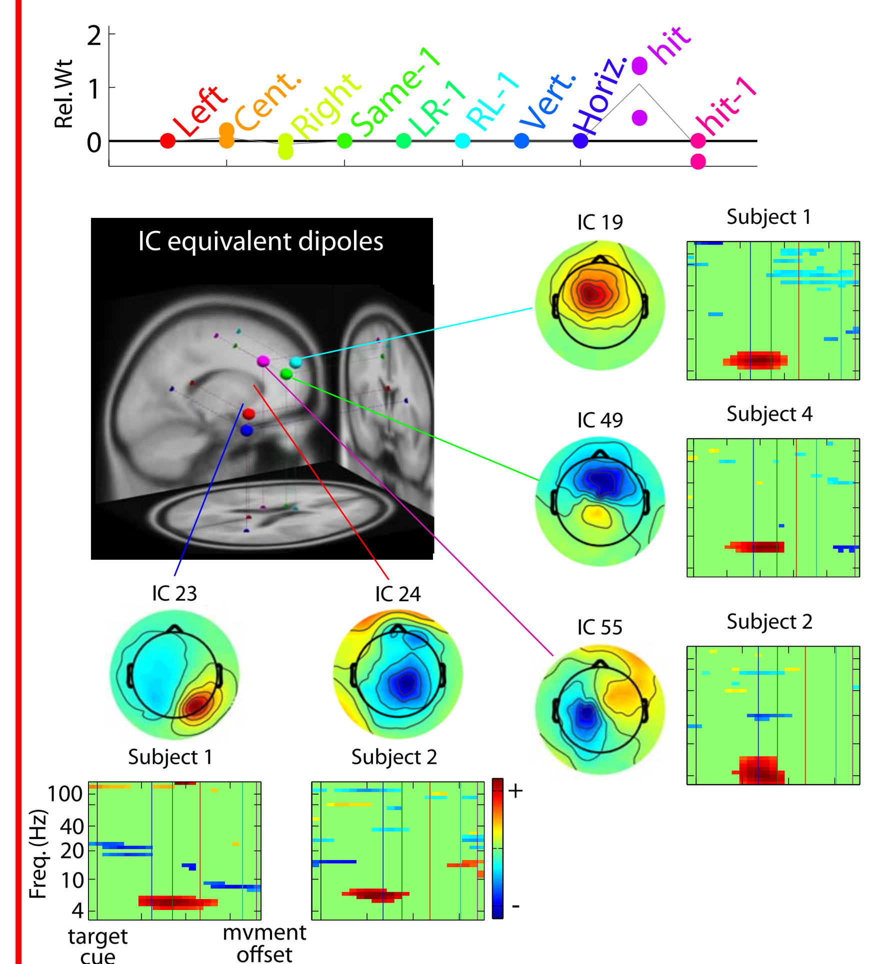


Figure 4. For at least five ICs from three of the subjects shown above, trials in which the subject hit the target (at epoch end) were associated with theta band power increases during the reach movement onset phase (blue line) until the max acceleration point (green line). In possible consistency with this result, frontal midline theta bursts have been previously associated with concentration.

3) Effects of starting pose

(other subjects)

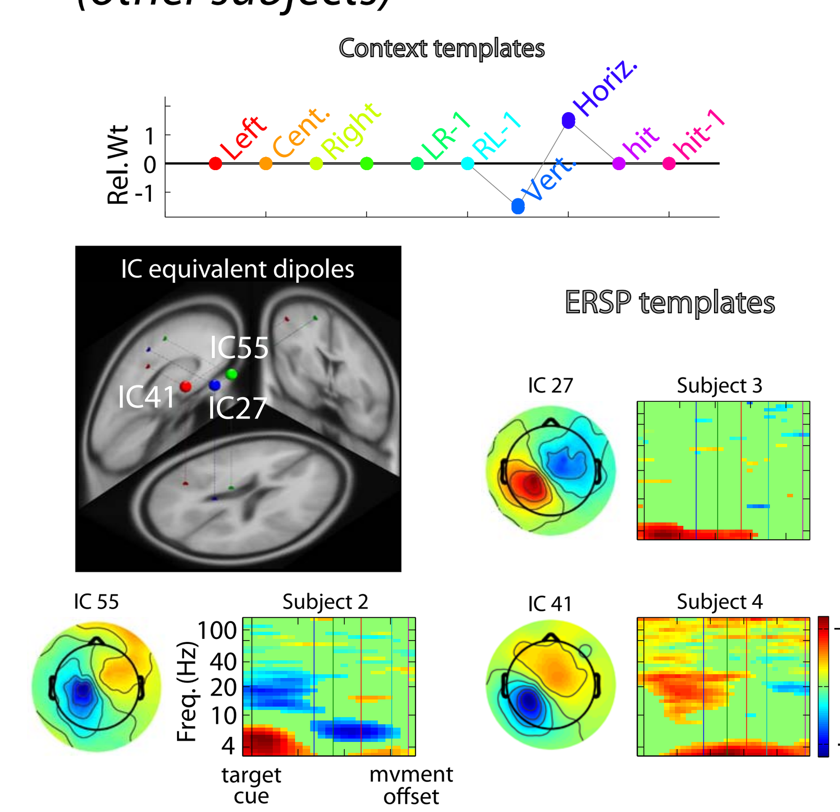


Figure 5. Factor context templates associated with starting pose for left central ICs from three subjects contained larger ~4-Hz activity before and/or during reaches starting from the horizontal pose (compare with Fig. 1).

2) A more complex context template

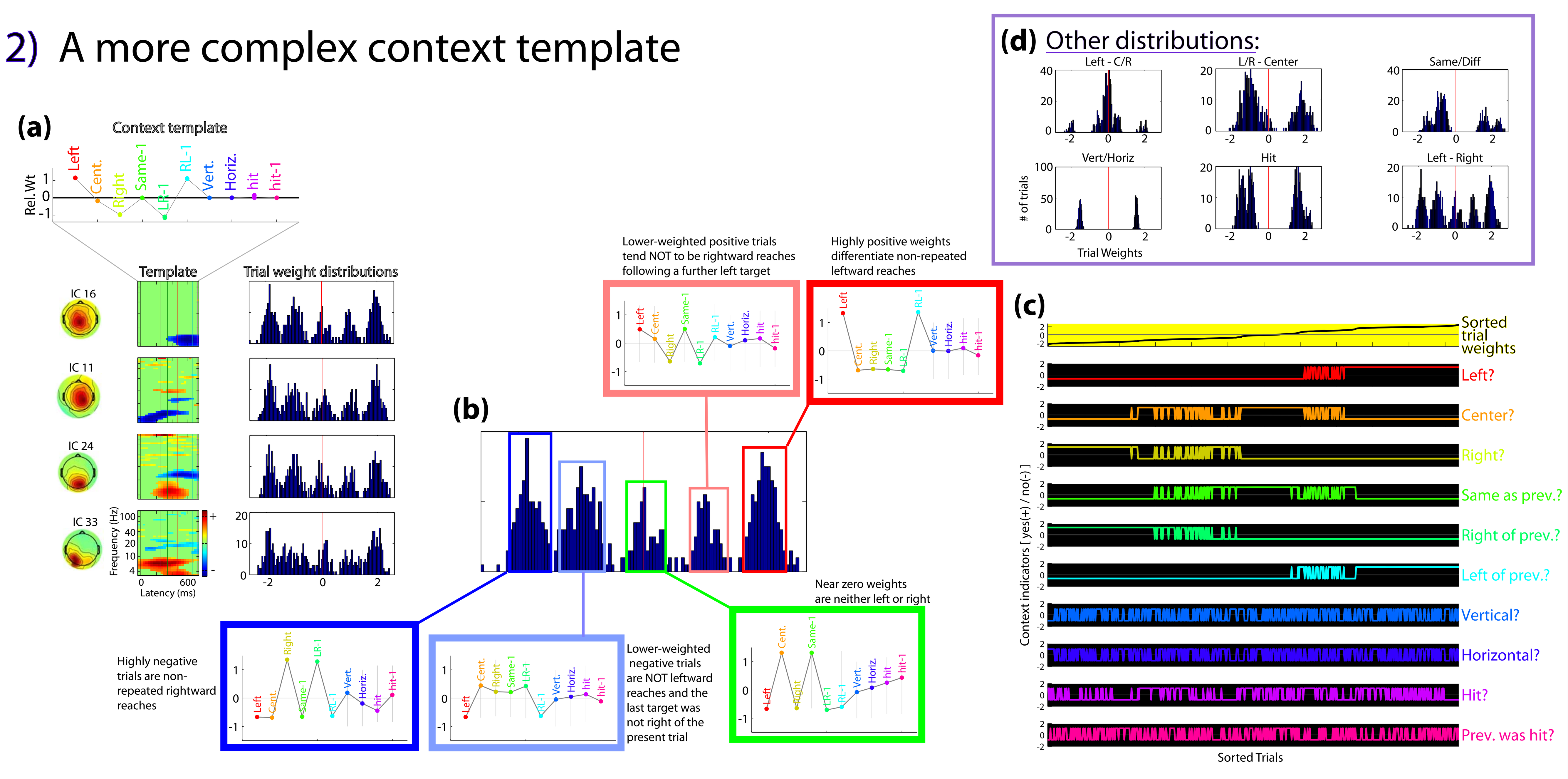


Figure 2. **(a)** This context template (2nd left col.), returned for the four ICs shown, loads + on left (and - on right) reaches, particularly when the current reach is to the left of the previous reach target (i.e., less so when the previous reach was also to the left). This separates the trials into 5 classes (weight histograms, 3rd left col.). **(b)** For the topmost IC16, examination of the mean context answers for trials in each of the 5 classes, shows how the non-zero weighted questions affect the weight on this template. **(c)** Plotting the question values for each of the trials, sorted by its weight for this context factor, shows how the 5 trial classes were selected by xICA. Answers to questions irrelevant to this context template (lower four rows) are randomly ordered by these factor weights. **(d)** Trial weight histograms for other factors have similar patterns.

SUMMARY

1. Specific (+ and - weighted) variations in stimulus-locked ERSPs for ICs many cortical areas accompany specific phases of 3-D reaching movements.
2. For these data, weights on the ERSP modulation factors returned by context ICA (xICA) co-varied with trial type -- as defined by answers, for that trial, to the ten event context questions entered into the decomposition.
3. Using high-density EEG for mobile, high-definition brain imaging appears promising.

Human Brain Mapping, 2007 chicago