Supporting Information

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SI Methods

Participants. Sixteen right-handed neurologically healthy adults (seven females, 20–32 years old) participated in the study (16 in Experiment 1; 3 of those 16 in Experiment 2; see refs. 1 and 2, respectively). The study protocol was approved by the Johns Hopkins Medicine Institutional Review Board, and informed consent was obtained from all participants.

Apparatus. Stimuli were rendered in white on a black background using MATLAB (MathWorks) and Psychophysics Toolbox (3) (for Experiment 1) and custom C coded software (for Experiment 2), and were projected onto a screen mounted to the top of the magnet bore behind the subject's head. Subjects viewed the screen reflected from a mirror at an optical distance of 68 cm. Subjects held MR-compatible response boxes with their left and right hands. A custom-built MR-compatible infrared camera was used to monitor eye position during the task; the video signal was recorded with the ViewPointEyeTracker software (Arrington Research).

Imaging Acquisition and Processing. MRI scanning was carried out with a Philips Intera 3T scanner in the F.M. Kirby Research Center for Functional Brain Imaging at the Kennedy Krieger Institute, Baltimore, MD. Anatomical images were acquired using an MP-RAGE T1- weighted sequence that yielded images with a 1-mm isotropic voxel resolution (TR = 8.1 ms, TE = 3.7 ms, flip angle = 8°, time between inversions = 3 s, inversion time = 738 ms). These anatomical scans were acquired in each session and used to coregister between session (two sessions for Experiment 1 and three sessions for Experiment 2). Whole brain echoplanar functional images (EPI) were acquired with an six-channel SENSE (MRI Devices, Inc.) parallel-imaging head coil. In Experiment 1, EPI data were acquired in 40 transverse slices (TR = 2,000 ms, TE = 35 ms, flip angle = 90°, matrix = 64 × 64, FOV = 192 mm, slice thickness = 3 mm, no gap), while in Experiment 2, EPI was acquired in 35 transverse slices (TR = 2,000 ms, TE = 30 ms, flip angle = 70°, matrix = 64 × 64, FOV = 192 mm, slice thickness = 3 mm, no gap). Voxel size was consistent across experiment. Neuroimaging data were analyzed using BrainVoyager QX software (Brain Innovation). Functional data were slice-time and motion corrected and then temporally high-pass filtered to remove components occurring three or fewer times over the course of a run. To correct for between-scan motion, each subject's EPI volumes were all coregistered to that subject's anatomical scan.

Behavioral Task: Experiment 1. Subjects were instructed to maintain fixation at a central fixation point throughout each run. Two rapid serial visual presentation (RSVP) target streams of alphanumeric characters (250 ms per frame with no temporal gap) were located 4° of visual angle below the horizontal meridian and 4° to the left and right of the vertical meridian. Each target stream was flanked by three distractor streams with an edge-to-edge separation of 0.5° (Fig. 1*A*). The distractor streams were included to compete with the target streams and maximize attention effects. At any given moment, the subject covertly attended to either the left or right RSVP target stream and was prepared to categorize target digits that appeared in the attended location by one of two rules: odd vs. even (Parity Task) or high (6–9) vs. low (2–5) (Magnitude Task). Forty-eight critical events were randomly intermixed among filler items (non-cue letters) in each run; half of those were letter cues (i.e., 'L','R','M','P') and half were target digits (i.e., 2–9). Cue and target events were separated in time by 3–9 s with an average of 6 s between them. Cues and targets were presented in a random order. Cues and targets did not appear in the currently ignored target stream. The four letter cues respectively specified L: "attend to the target stream on the Left," R: "attend to the target stream on the Right," M: "prepare for the Magnitude task," and P: "prepare for the Parity task." Subjects were trained to respond to the cues by pressing buttons simultaneously with both index fingers (i.e., the response was the same for all cues), and to respond to target digits with either the left or right middle finger depending on their trained stimulus-response mappings (e.g., even and high: left button; odd and low: right button; the mapping was counterbalanced across subjects). Missed cues or targets and incorrect target categorizations were excluded from the neuroimaging analysis. Each run in the scanner lasted for 308 s. Subject completed an average of 24 runs over two scanning sessions on two different days. Eye position was monitored during scanning to ensure fixation. The 2 (Domain of Control: spatial attention vs. categorization rule) × 2 (Trial Type: shift vs. hold) design resulted in four cue conditions—attention-shift (attSh), attention-hold (attHd), categorization rule-switch (rulSw), and categorization rule-hold (rulHd).

Behavioral Task: Experiment 2. Subjects continuously fixated a central white dot while observing a display consisting of six white RSVP streams of letters on a black background (Fig. 1*B*). Two target streams fell on the horizontal visual meridian, at 10° of visual angle to the left and right of the fixation point. Distractor RSVP streams (which never contained cue letters) appeared above and below each target stream, at the same distance from fixation. All RSVP streams were presented synchronously at a rate of four items per second (250 ms per frame with no temporal gap).

The four cue letters respectively specified L (location): "shift visuospatial attention from the attended target RSVP stream to the other target RSVP stream (left to right or right to left)," C (counter): "switch from one counter to the other counter being maintained in working memory," P (plus): "add one to the selected counter's value," and H (hold): "maintain the current states of visual attention, counter selection, and counter values." Subjects were instructed to press the buttons they held in each hand whenever they detected a letter cue. Cues were presented only in the attended RSVP stream.

Subjects maintained two counters in WM, whose values were initially set to zero. Cue letters appeared with a pseudorandomly selected interstimulus interval (ISI) of 2.5, 4, 5.5, or 7 s; the average ISI was 4.75 s. Cues appeared in a pseudorandom order. All four cue letters and all four ISIs appeared an equal number of times in each run—15, 16, or 17 times. The run length thus varied as a result of the number of items in the run—this was done so that the final counter values would be unpredictable from one run to the next. At the end of the run, subjects verbally reported the values of the two counters.

Importance Map. The SVM returns a weight for each voxel, such that the weighted sum of the voxels (plus a Bias term) yields a decision value that is compared to a decision boundary, in this case zero. In Experiment 1, positive weights were assigned to voxels whose activity tended to be large during attention shifts, and negative weights were assigned to voxels whose activity tended to be large during rule switches. With linear SVM, the absolute value of each voxel's weight provides a quantitative index of the importance of that voxel in the decision function (4); the most discriminating feature (i.e., voxel) has the largest absolute weight. Importance maps were computed by ranking the voxels according to the absolute value of their weights.

Randomization Statistics. We used randomization statistics to test for significance within each of the three subjects in the cross-experiment study, because group level statistics lack power with only three participants. Test trial labels were shuffled randomly and the classification was performed; this was then repeated 1,000 times, generating a distribution of classification rates that would occur purely by chance (with an overall mean of 50% as a group). The mean and standard deviation of this random distribution for each subject served as the basis for a determining a critical value, such that any observed value that exceeded the critical value could be assigned a probability $P < 0.05$ (one-tailed) under the null hypothesis.

1. Chiu YC, Yantis S (2009) A domain-independent source of cognitive control for task sets: Shifting spatial attention and switching categorization rules. *J Neurosci* 29:3930–3938.
2. Rosenau BJ, Esterman M, Chiu Y-C, Yantis S (2009) A domain-independent source of cognitive control for shifting attention in vision and working memory. *Journal of Vision* 9(8):164, 164a.
3. Brainard D (1997) The Psychophysics Toolbox. *Spatial Vision* 10:433–436.
4. Norman K, Polyn S, Detre G, Haxby J (2006) Beyond mind-reading: Multi-voxel pattern analysis of fMRI data. *Trends Cognit Sci* 10:424–430.

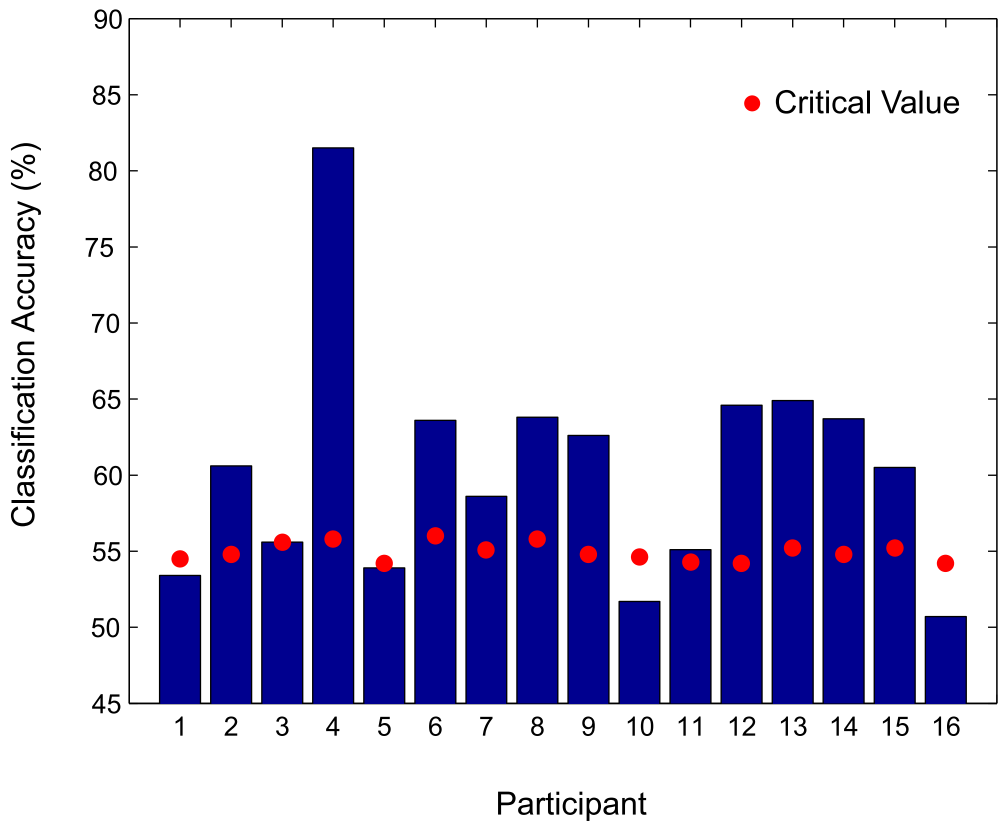

Fig. S1. Classification of attention shifts and rule switches, Experiment 1. Classification rate in mSPL for all 16 participants. Red dots indicate critical value for each subject separately from a randomization test ($P = 0.05$; see *SI Methods*). For 12 out of 16 subjects, classification rate is greater than chance (binomial test, p(success) = .05, $P < 10^{-14}$).

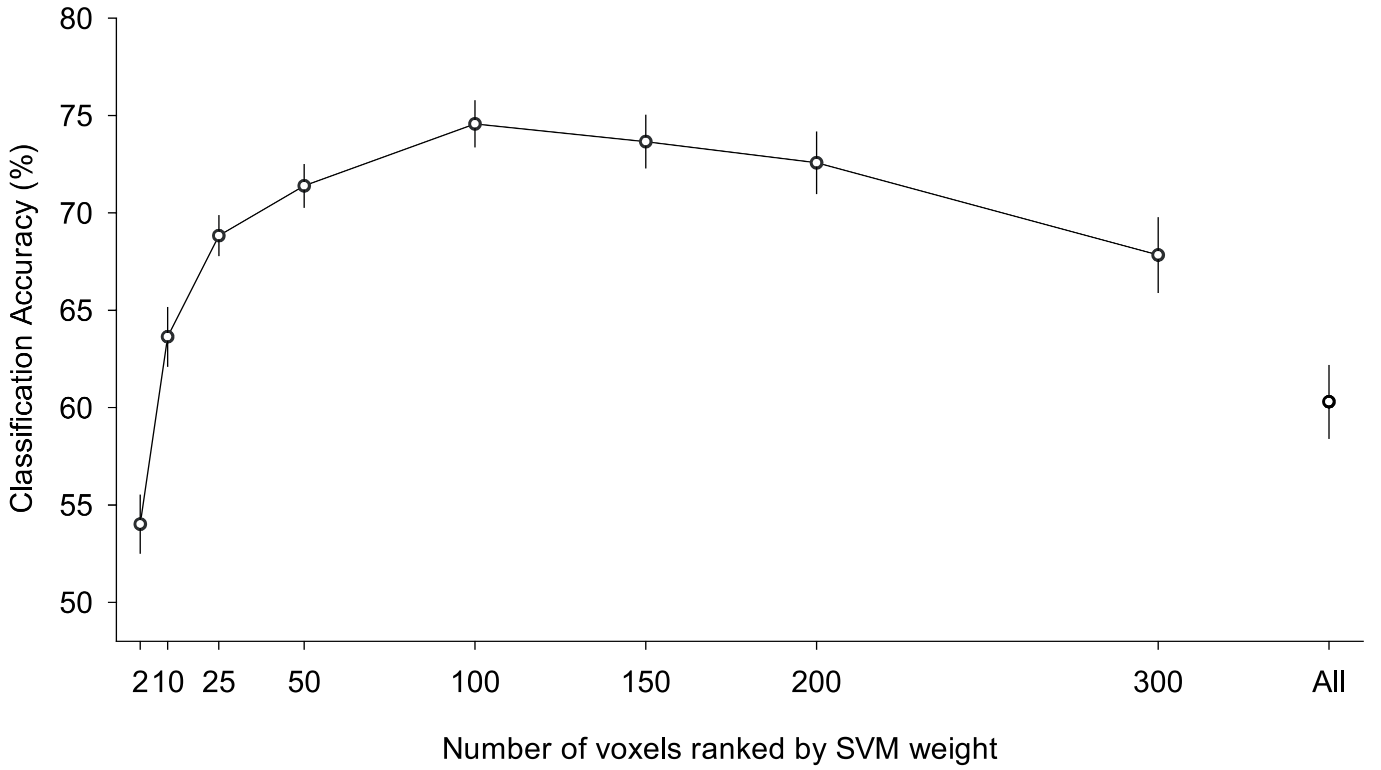

Fig. S2. Classification performance as a function of the number of voxels included in the analysis, where voxels are rank ordered by importance (absolute magnitude of linear SVM weights). Classification performance peaks with the best 100 voxels. Weights are determined nonindependently, because the results of all leave-one-run-out classifiers are used to compute weights and rank voxels.

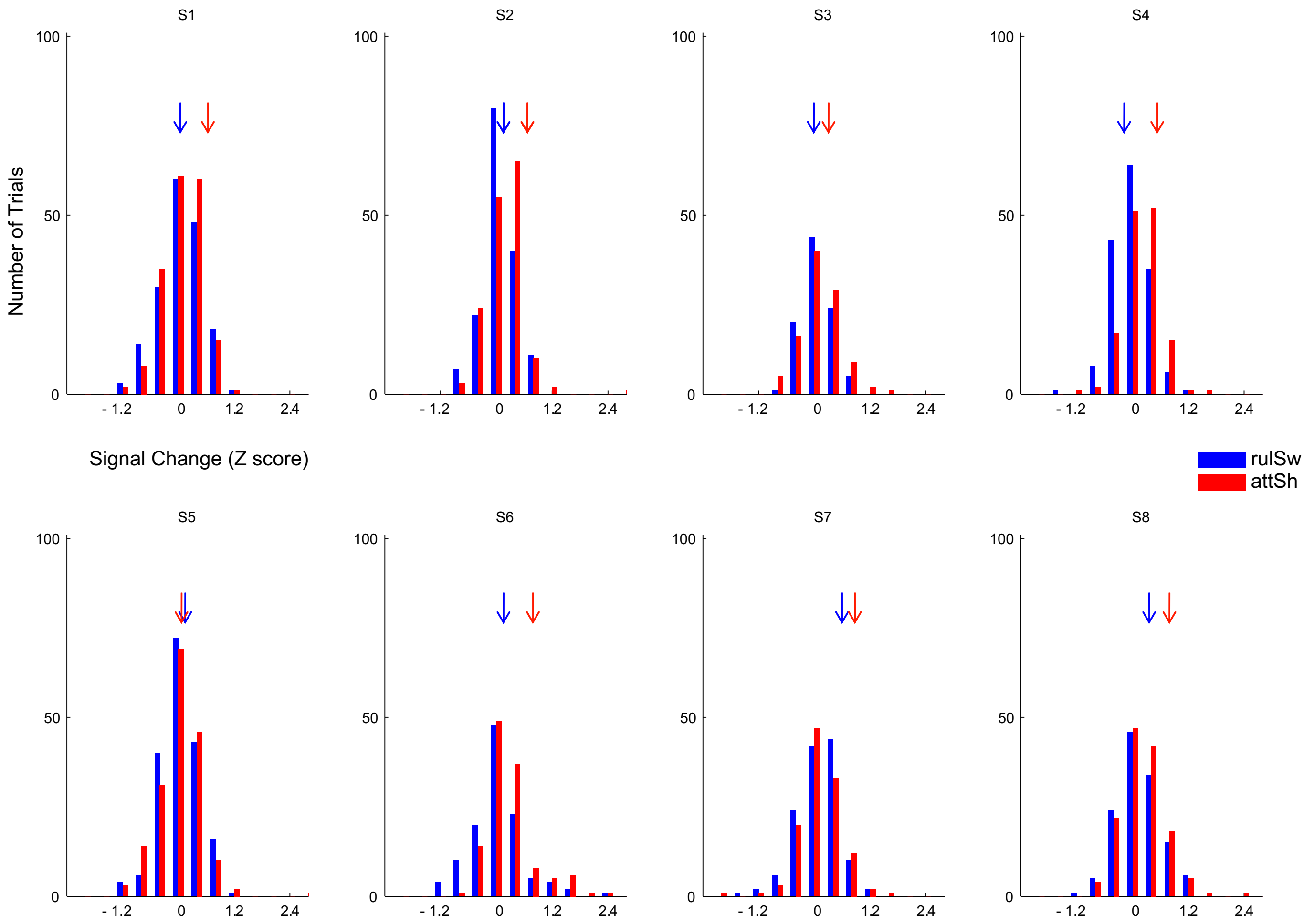

Fig. S3. Histogram of evoked response within mSPL for attention shifts and rule switches. Separate plots for each subject, demonstrating overlapping distribution of mSPL responses for both types of switches. Arrows indicate the mean of each type of switch across trials.

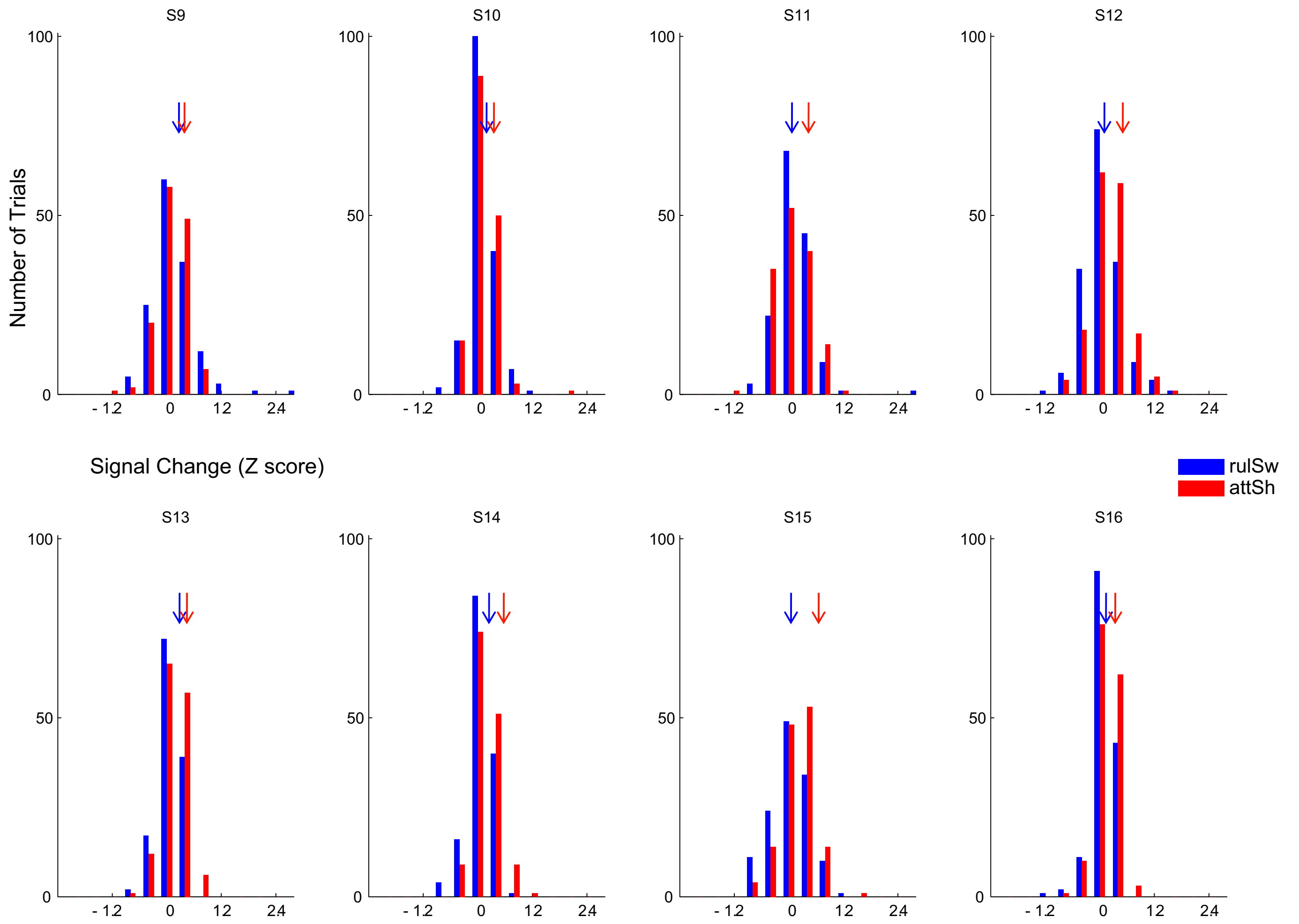

Fig. S3. Continued.

Supplementary Figure 4

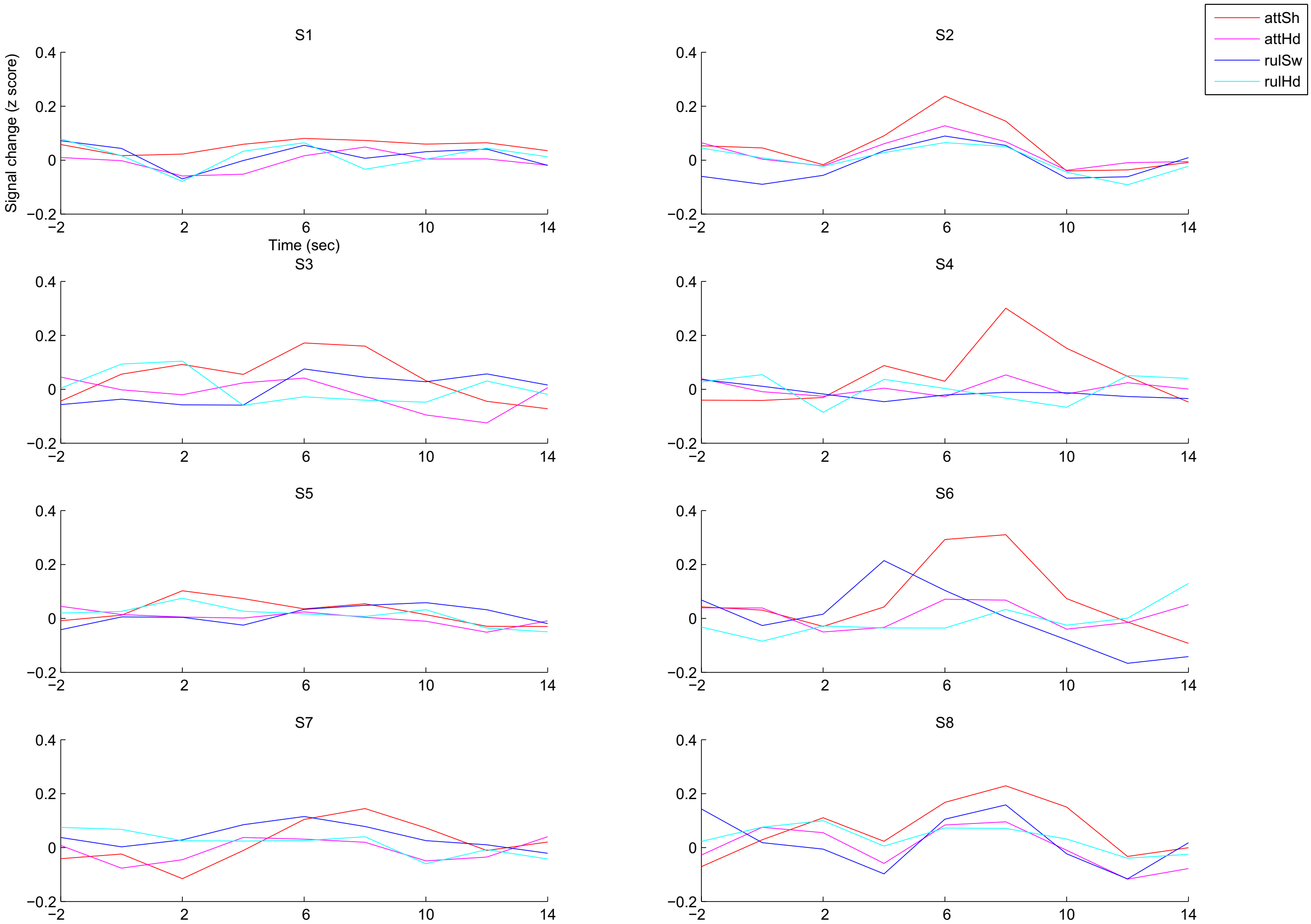

Fig. S4. Switch-evoked time course. Separate plots for each subject, demonstrating transient mSPL BOLD response for attention and rule switches, as well as hold events.

Supplementary Figure 4

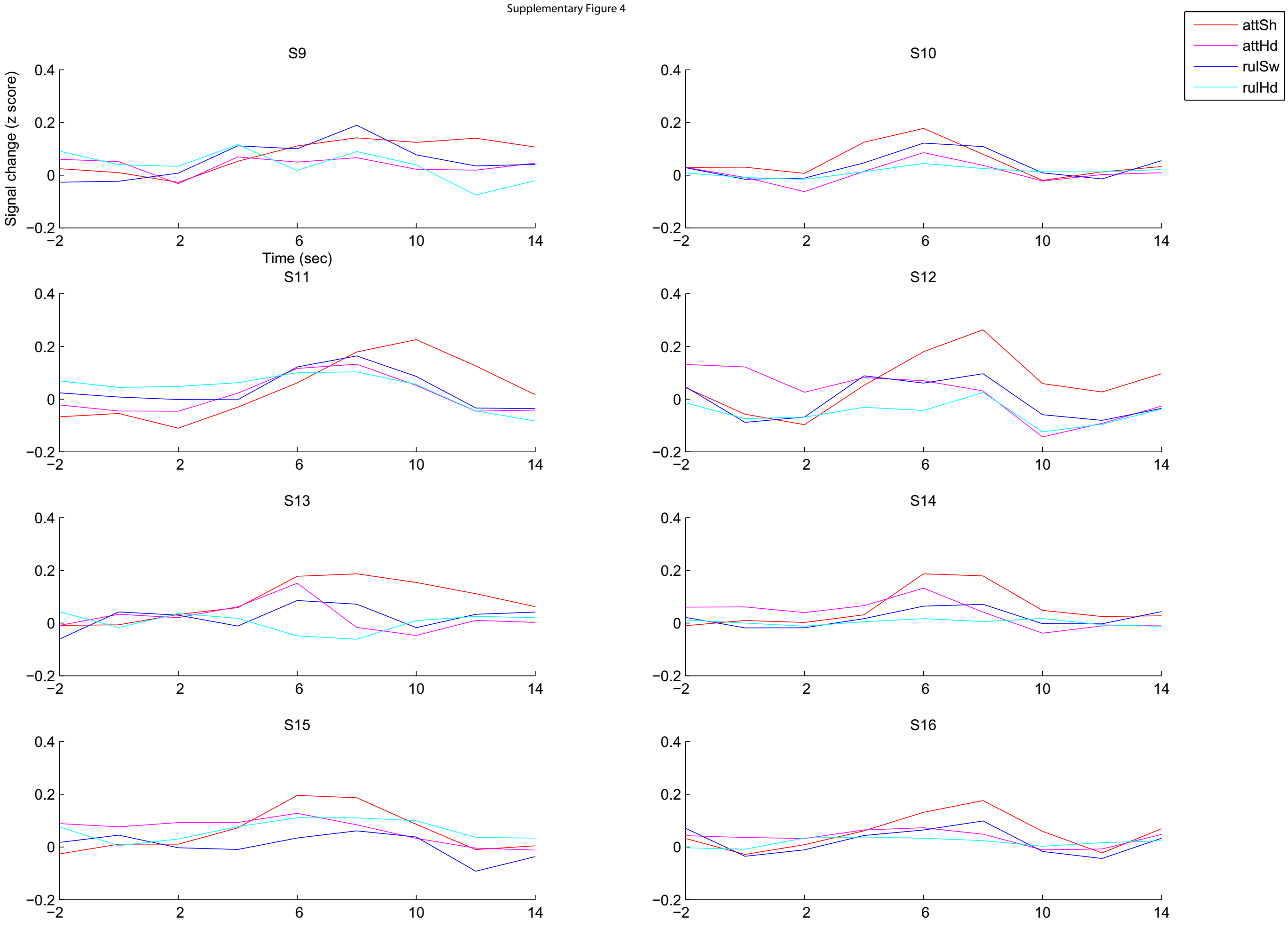

Fig. S4. Continued.

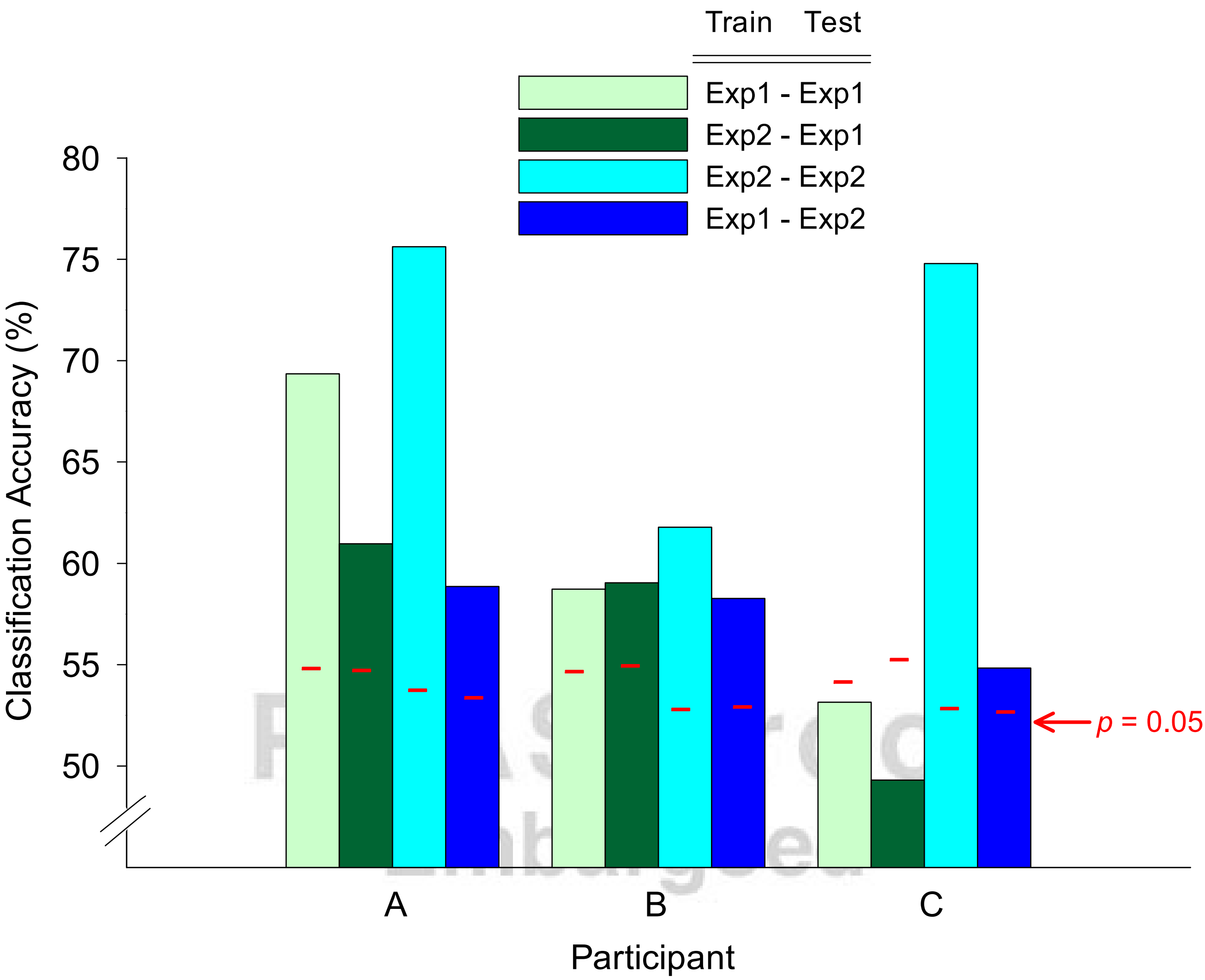

Fig. S5. Within and across experiment classification. The following data are after mean-centering procedure (see *Methods*). In two of three subjects, classification performance is significantly greater than chance (red lines indicate the critical value from a randomization test, $P = 0.05$; see *SI Methods*) for classification within Experiment 1 (light green) and three of three within Experiment 2 (light blue). When data from Experiment 1 were used to train a classifier to predict switches in Experiment 2, decoding was significantly greater then chance in all three subjects (dark blue). When data from Experiment 2 were used to train a classifier to predict switches in Experiment 1, decoding was significantly greater than chance in subjects A and B, but not C (dark green).