Neural activity involved in the perception of human and meaningful object motion

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We characterized magnetoencephalographic responses during observation of point-light displays of human and object motion. Time courses of grand-mean source estimates were computed and time frequency maps were calculated. For both conditions, activity began in the posterior occipital and mid-parietal areas. Further, late peaks were observed in the parietal, sensory-motor and left temporal regions. Only observation of human motion resulted in activation of the right temporal area. Both viewing conditions resulted in α and β event-related desynchronization over the parietal, sensory-motor and temporal areas. A significant increase in β activity was seen in the posterior temporal region in the human motion condition. The visual analyses of human and object motion appear to involve both overlapping and divergent patterns of neural activity. *NeuroReport* 18:1125–1128 © 2007 Lippincott Williams & Wilkins.

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Introduction

Social behavior frequently depends upon inferences that are based on the perception and interpretation of other people's actions. Given the fundamental importance of accurately perceiving socially relevant information, one might predict that specialized mechanisms subserve the visual perception of human action [1]. Numerous studies have suggested that the posterior region of the superior temporal sulcus (STSp) plays a central role in the visual analysis of human movement [2–4]. New evidence from imaging research, however, indicates that it may be more appropriate to consider the perceptual analysis of human movement as a network of cortical areas that includes STSp. Neural areas involved in motor planning, such as the primary motor cortex and the premotor cortex, are also responsive during the perception of human movement (see Refs. [5–7]). Indeed, action comprehension is thought to involve activation of neural substrates that are employed in planning the execution of the observed action, suggesting a common coding between perception and action (see Ref. [8]). In humans, observation and execution of grasping and simple finger movements both activate Brodmann area (BA) 44 or 45 [9–11]. These and other studies imply the existence of a complex network of cortical areas involved in the visual perception of human action [3,12,13].

One approach used to study the perception of action involves point-light stimuli [14], in which complex dynamic events are reduced to the movements of a few points strategically positioned on the joints or corners of moving people or objects (Fig. 2 inset). Point-light stimuli are unrecognizable when presented statically but are rapidly recognized once set in motion. Thus, point-light displays clearly depict action cues but only depict very sparse and largely unrecognizable cues to static form. Previous studies have contrasted upright and inverted displays of human motion that controlled for spatial frequency and motion information [14–16]. As, however, inverted displays, have unfamiliar forms, the brain regions identified could reflect differences in the ease of processing familiar versus unidentified objects and may not specifically relate to human motion. Here we contrast brain activation induced during the observation of human motion and meaningful object motion. If motion-processing pathways are specific to the perception of human motion, the same structures should be engaged. Differences would reveal neural processes specific to human motion perception.

Materials and methods

Study participants

Six healthy right-handed adult participants (three men, three women) aged 20–40 years participated in this study. All participants provided informed, written consent and had normal or corrected to normal visual acuity. This study was approved both by the Simon Fraser University Research Ethics Board and the Down Syndrome Research Foundation Research Ethics Committee and conducted in accordance with the Declaration of Helsinki.

Stimuli

The stimuli consisted of 1-s movies depicting point light displays [14] of human motion and object motion. A three-dimensional VICON motion capture system (Oxford, UK) was used to measure the motions of various

human actors and moving objects. The resulting motion capture data were converted into point-light movies. The human motion consisted of six dots representing the head and limbs. The human figure was seen walking, jumping, running, twirling or hopping. The object motion was also represented by six dots and included a variety of common objects such as a moving office chair, frisbee and wheel. The dots in the object motion condition followed a variety of dynamic trajectories including linear, circular, periodic and nonlinear motions (Fig. 2, inset). The size and luminance of the dots in both conditions remained constant.

Procedure

A randomized set of 100 movies containing both types of stimuli was presented. Participants were asked to fixate visually a point in the center of the screen. After each movie ended and disappeared from the screen, participants pressed a button to indicate whether they had seen human or object motion. To time-lock the onset of the movement, a photo-sensitive diode was inserted on the screen to detect changes in luminance and triggered at onset of the video presentation. This trigger was simultaneously recorded with the magnetoencephalographic (MEG) signals.

Data recording and analysis

Participants were seated in an electromagnetically shielded room (Vaccumschmeltz, Hanan, Germany). Cortical responses were recorded with a 151-channel whole head MEG system (VSM MedTech, Coquitlam, BC). Signals were sampled at a rate of 600 Hz with a 150 Hz antialiasing filter and third gradient noise correction (final bandwith 0–150 Hz). Only correct responses were used for the analysis. The average correct response was 98%. Epochs extending from 200 ms before 1.5 s after display onset were selected and analyzed with Brain Electrical Source Analysis (BESA, Gräfelfing, Germany) 5.1 MEGIS Software GmbH, All epochs of MEG activity were first manually inspected for artifacts. Trials with excessive motion artifact were excluded. Eye motion artifacts were then corrected using standard procedures implemented in BESA software. About 75–85% of trials were retained from each participant.

Each individual participant's MEG data were averaged in time relative to the trigger. A group average was then created from the individual data sets for each condition. A source montage was used to transform the MEG activity obtained from all 151 channels into estimated contributions of a set of 15 separate brain regions to model. The 15 brain regions include a posterior medial occipital source and bilateral sources in the anterior and posterior temporal, parietal, frontal, and central areas. These 15 discrete regional sources were placed in a generic best-fit sphere-head model. It should be noted that the use of a source montage is not equivalent to performing a dipole fit. Regional sources used in BESA do not provide precise anatomical information but represent the data in brain source space. The reconstructed waveforms are based on the modeled source activities with units of current dipole moment (nAm) [17]. This 15-source model was applied to the group average data and resulted in a time course of source strength at each regional source for each condition. Time–frequency maps were computed with BESA coherence module. Single trials were transformed into the time-frequency domain using complex demodulation in the 5–60 Hz range at 1 Hz intervals using a 200 ms baseline before the onset of the trigger to 1.5 s after the onset. From the single trials, time-frequency displays were generated by averaging spectral density amplitude over trials. Probability maps were computed to test for significant differences between the two conditions in the temporal-spectral evolution using 999 bootstrap samples.

Results

From the source montage of 15 brain regions, the grand average source waveforms were calculated for both conditions. Figure 1 shows the grand average source waveforms plotted as a function of time from seven brain regions identified as regions of interest from previous studies. These include the occipital, central (corresponds to sensory-motor area) left, right and middle parietal and bilateral temporal regions. During the first 200 ms after stimulus onset, peak activity was observed primarily in the occipital and mid-parietal regions. In the object motion condition a peak was observed at 70 ms in the occipital region followed by a parietal peak at 80 ms. Subsequent peaks were observed in the occipital area at 135 ms and a second peak in the parietal area at 180 ms. For the human motion condition, there was an occipital peak at 85 ms, followed by a parietal peak at 100 ms and subsequent peaks in the occipital (135 ms) and parietal (180 ms) areas.

Between 200 and 400 ms, major peaks were observed in the sensory-motor, parietal and temporal regions. For both conditions, there was a peak in the sensory-motor region at 320 ms and in the (R) parietal area at 310 ms. A peak was observed at 356 ms in the (L) temporal region for the human motion condition and a smaller peak in the object motion condition occurring at 370 ms. In the (R) temporal region, a peak at 356 ms was observed in the human motion condition only.

Figure 2 shows the grand averaged time frequency plots from left and right parietal, temporal and sensory-motor regions based on the source montage for both conditions for the α (8–15 Hz), β (15–35) and γ (35–60 Hz) frequency bands in the human motion (a) and object motion (b) conditions. Blue areas indicate areas of significant event-related desynchronization (ERD) and red areas indicate areas of event-related synchronization. Stimulus onset is at 200 ms. In the top panel, α-ERD can be seen in the right sensory-motor, middle, right parietal and left posterior temporal regions. Although not shown, we also observed α-ERD in the occipital region in both conditions. Beta-ERD can be seen in the right parietal and right temporal regions. Gamma-ERD is only observed in the right temporal region. In the object motion condition, α-ERD can be seen in all regions with the exception of the right temporal area. β-ERD is seen in the left temporal, left and right parietal and right sensory-motor regions. γ ERD is predominantly seen in the right sensory-motor region.

Computation of probability maps to test for significant differences between the two conditions in the temporal-spectral evolution revealed only one area that reached a statistically significant difference ($P<0.05$). An increase in the β band in the left posterior temporal region was seen between 250 and 350 ms ($P=0.003$).

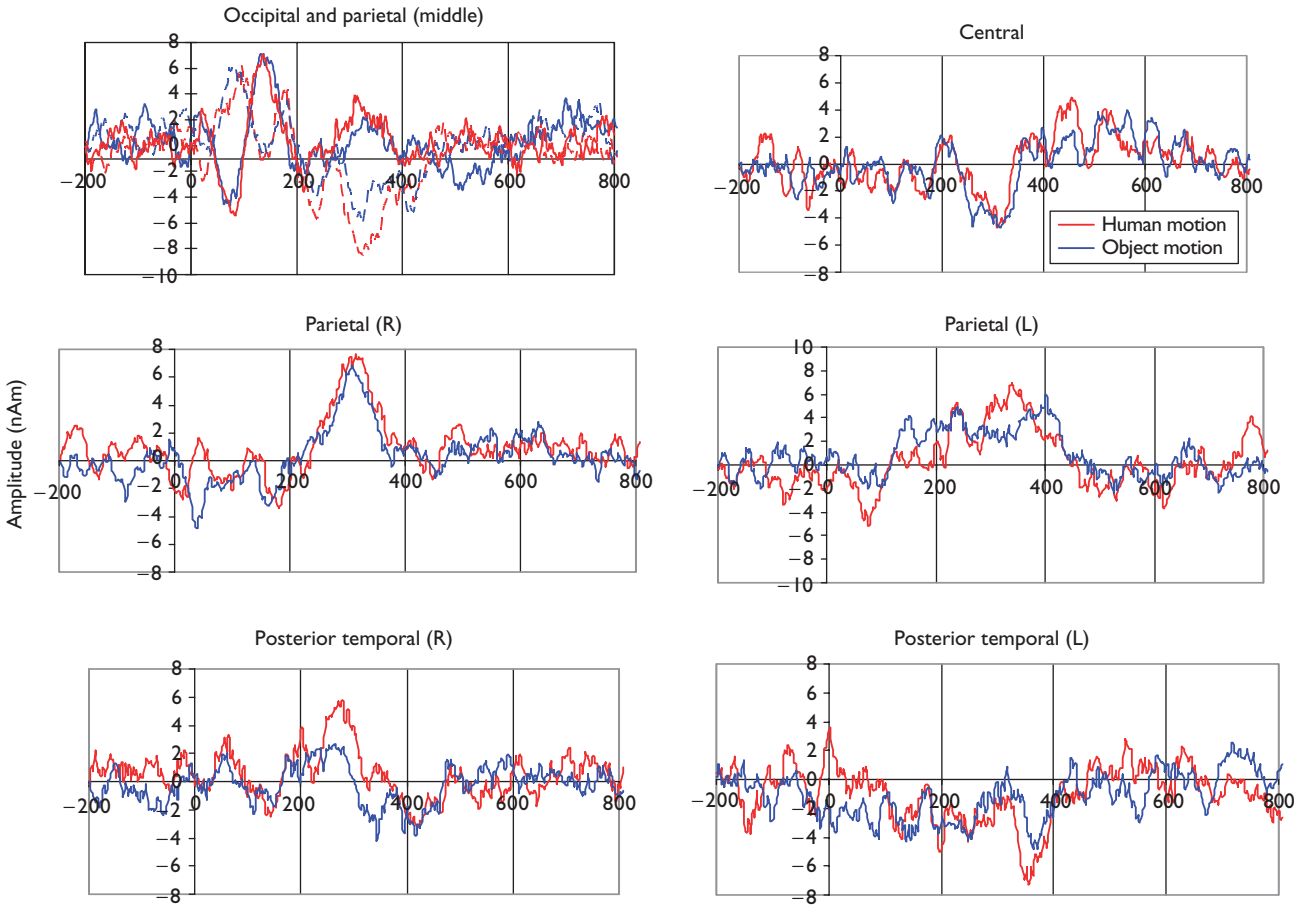

Fig. 1 Grand average source strength plotted as a function of time based on 15 regional sources for the human motion and object motion conditions in the occipital, parietal and temporal areas. Dotted lines represent activity from the mid-parietal regions.

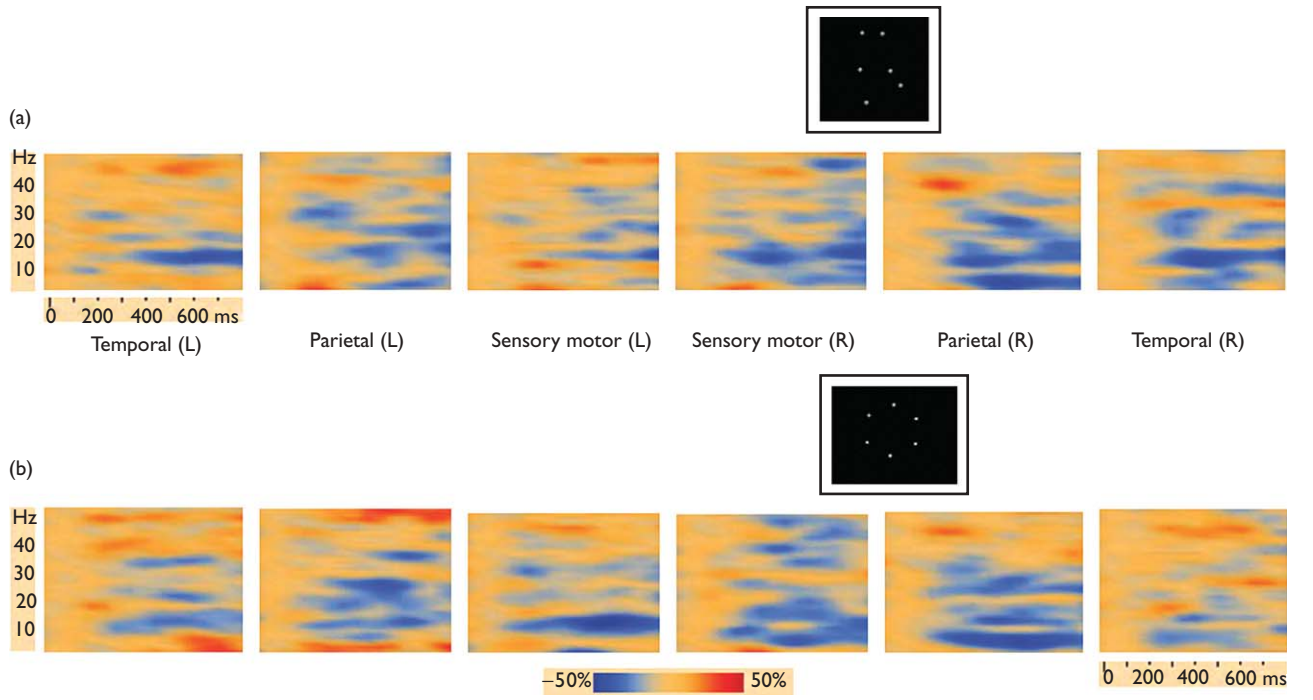

Fig. 2 Grand-averaged time-frequency plots from left and right parietal, temporal and sensory-motor regions in the human motion (a) and object motion (b) conditions.

Discussion

Under both experimental conditions, early time-locked components were observed in the occipital and mid-parietal regions and further late peaks were observed in the parietal, sensory-motor and left temporal regions. Only observation of human motion resulted in late activation of the right temporal area. The time-frequency maps indicated that both object and human motion were associated with ERD of the α- and β-frequency band (8–35 Hz) in the occipital, sensory-motor, parietal and temporal regions. Substantial research suggests that ERD of α and β rhythms is correlated with increased neuronal activation whereas event-related synchronization is associated with decreased cortical excitability (e.g., Ref. [18,19]). In addition, whereas lower α-desynchronization (7–10 Hz) is thought to reflect general attention-related processing, upper α desynchronization (10–13 Hz) appears related to task-specific processing [19,20]. This would suggest that the upper α- and β-band ERD observed in this experiment may be interpreted as a functional network involving occipital, sensory-motor and left temporal regions involved in processing both human and object motion.

Another key difference between the two conditions was activity in the γ band. In the human motion condition, γ activity (35–60 Hz) was only observed in the right temporal region from approximately 200 ms after stimulus onset. In contrast, γ activity was only observed in the right sensory-motor region in the object motion condition, starting from the onset of the stimulus to approximately 400 ms. Gamma electroencephalogram and MEG activity has been associated with cognitive processes including visual perception and attention (for review see Ref. [21]). In terms of visual perception, γ activity is thought to be associated with the processing of Gestalt-like or meaningful patterns (e.g., Refs [22–24]). Previous MEG results have indicated γ-activity in parietal and right temporal areas only in response to recognizable displays of human gait [17].

Conclusion

The results of this study indicate that during early temporal stages of neural processing, the perception of human motion and object motion share overlapping cortical networks involving the occipital, parietal and sensory-motor regions. The perception of human motion appears to diverge from the perception of object motion during subsequent temporal stages as high-level visual processes in the posterior temporal region are selectively triggered during human motion perception. Thus, although the human body is ultimately a physical object and could be analyzed as such, neural processes appear to differentiate human motion from object motion in late stages of analysis.

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