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## INFANT PERCEPTION OF HUMAN ACTION: TOWARD A DEVELOPMENTAL COGNITIVE NEUROSCIENCE OF INDIVIDUAL DIFFERENCES

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### **ABSTRACT**

*The aim of this study was to investigate individual differences in the development of the ability to perceive human action. We examined: (1) the environment provided by mothers (as indexed by maternal motionese); (2) infant motor abilities; and (3) infant processing of biological movement (as indexed by looking times and gamma-band time-frequency analysis of EEG). In Experiment One it was found that, as a group, eight-month old infants looked longer at video clips of impossible body movements than possible movements. However, this effect was mainly due to the subset of infants with relatively high fine motor skills. In Experiment Two, Gamma frequency analysis of EEG resulting from passive viewing of possible and impossible action indicated that only those infants with relative high fine motor skill processed these stimuli differently. When taken together, these studies suggest a potential relationship between the infant's own ability to perform fine motor action and the perception of biologically possible human movement.*

**KEY-WORDS:** *Gamma oscillations, biological motion, infants, EEG, action perception*

### **INTRODUCTION**

Movement of the human body conveys social signals that often require immediate recognition. Human actions are an exceedingly complex set of stimuli, yet infants appear to be able to process and interpret this information to at least some degree. Even infants at 3 months are able to discriminate aspects of this

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seemingly complex information (reviewed in Bertenthal, 1993). Despite these quite impressive early competencies, understanding of the inherent physical limitations of the human body continues to develop into toddlerhood (Slaughter, Heron & Sim, 2002).

Perhaps the most basic form of biological knowledge may be an understanding of typical human body shape. Slaughter et al. (2002) proposed that infants are born with an amodal body schema that allows infants to map the similarity between themselves and other people. These authors presented infants with two sets of human body pictures whereby one condition featured normal human bodies in different poses, whereas the second condition contained human bodies with scrambled gross anatomy, such as arms replaced with legs. During a standard infant preferential looking time paradigm, the authors found that there was a preference among infants of 18 months for scrambled body shapes. There was no preference, however, for either scrambled or normal body shapes in infants of 15- or 12- months, suggesting an inability to discriminate the conditions at these ages. These data imply that prior to 18 months of age, infants do not have expectations about the human body shape. The presentation of static human figures rather than moving stimuli may explain why Slaughter et al. (2002) found that only infants of 18 months or more have expectations about human body shape. Movement may facilitate disambiguation of the stimuli and therefore awareness of the human body shape.

Research into infant perception of biomechanical motion has been conducted for over twenty years. Initial studies such as Bertenthal, Proffitt, and Cutting (1984) utilised point-light-displays (PLDs), first used by Johansson (1973). Using such stimuli, infants as young as 3 months have been shown to be sensitive to configural information relating to movement (Bertenthal et al., 1984). Infants of 5 months have also been shown to discriminate PLDs in the configuration of a human when compared with a scrambled PLD, despite movement in each condition containing the same mathematical constraints between individual points of light. The biomechanics of limb motion have also been investigated with simple PLDs. Bertenthal, Proffitt, Kramer, and Spetner (1987) presented three light points to infants of five months, with each point of light representing the shoulder, elbow and wrist, respectively. In one condition, all three light points moved in a rigid transformation, appearing biomechanically possible. Another condition moved the PLD out of phase such that the arm display appeared to look disjointed, or biomechanically impossible. The infants successfully discriminated the locally rigid display from the out of phase display, suggesting some sensitivity to biomechanical constraints of the human body. What is clear about research with PLDs is that there is considerable change in infant perception of point light motion throughout the first year. Even though such stimuli may be useful in investigating the perception of movement, PLDs are unnatural and intrinsically novel for infants. Recent developments in computer technology allow for manipulation of still-frames from film, thereby allowing for the creation of real, human movements that are nonetheless biologically impossible. The issue of infant perception of

biological movement can now be addressed with naturalistic stimuli for the first time.

Research into infant perception of human biomechanics has never been investigated at the neural level. PET and fMRI studies *with adults* indicate, however, that during the perception of biological motion, the Superior Temporal Sulcus is activated (e.g. Castelli, Happe, Frith, & Frith, 2000; Grossman et al. 2000). Research has also been conducted investigating adult gamma band activity underpinning the perception of stable and non-stable body postures (Slobounov, Tutwiler, Slobounova, Rearick & Ray, 2000). The rationale for investigating this frequency was that gamma band activity increases during sustained attention, with previous studies indicating that this is a physiological correlate of selective attention (Müller, Gruber, & Keil, 2000). Slobounov et al. (2000) presented adult participants with an animated human body rocking backwards and forwards on the ankle joint. Swaying movements were presented as either stable or non-stable with participant reaction times indicating stability. Results from passive viewing showed that increases in gamma in fronto-central regions and parietal sites correlated with the recognition of postural instability. The change from baseline was shown to be slightly higher in the right hemisphere in the 30-50Hz frequencies. These results suggest that during visual perception, there are thresholds within human movement that are detectable within the EEG signal. As such, this would suggest the existence of neural detectors for biologically possible movements. What remains entirely unclear, in fact, uninvestigated, is the development of these thresholds for detecting biological movement and whether they can be identified via EEG in early development.

The present study will investigate infant perception of possible and impossible movements of the human body. It is predicted that the analysis of gamma-band frequency EEG will reveal activity in similar regions of the infant brain to those seen in adult participants when processing human movement. As previous studies with adults have indicated that the gamma frequency is a physiological correlate of selective attention (Müller et al., 2000), such differences may also be evident in the infant brain.

Even though the research findings considered in the beginning of this introduction suggest that infants learn about biological motion throughout the first postnatal year, they do not address individual differences and, in particular, whether such variation in perceptual processing of biomechanical information arises from differential exposure to specific visual information. Recent research suggests that parents present objects to infants in a different manner to how they present objects to other adults. This activity has been characterised by a deliberate enhancing of structure in object manipulation in order to afford infants greater understanding of the action involved in the object manipulation (Brand, Baldwin, & Ashburn, 2002). Such results suggest that the amount of exaggerated object manipulation, or *motionese*, that is displayed to infants is variable between infants, though this does not provide information about what aspect of visual experience is critical for the perception of biomechanical movement.

In the present investigation, we examined two potentially distinct factors that may predict variation in infant looking times and electrophysiological responses to stimuli. These are: (1) measures of infant motor ability and, (2) maternal methods of object presentation to infants (motionese). Conceivably, the effect of being reared by a mother greatly disposed to present objects using exaggerated actions may facilitate the detection of the physical limitations of the human body. It is also possible that the infant's own motor skills may relate to the perception of biological motion, for more advanced skills could reflect a better knowledge of the inherent constraints of the human body.

In order to assess infant sensitivity to characteristics of biological motion, we used both behavioral (visual preference, Experiment One) and electrophysiological measures (Experiment Two). We employ two distinct measures because the behavioral index provides an overt measure of how infants differed in the responses to the stimuli, whereas the electrophysiological index provides information about the timing and approximate location of the neurophysiological events that lead up to the behavioral response. The assessment of neural substrates related to the perception of biological motion thus far remains uninvestigated in an infant population.

## EXPERIMENT ONE

### METHOD

#### *Participants*

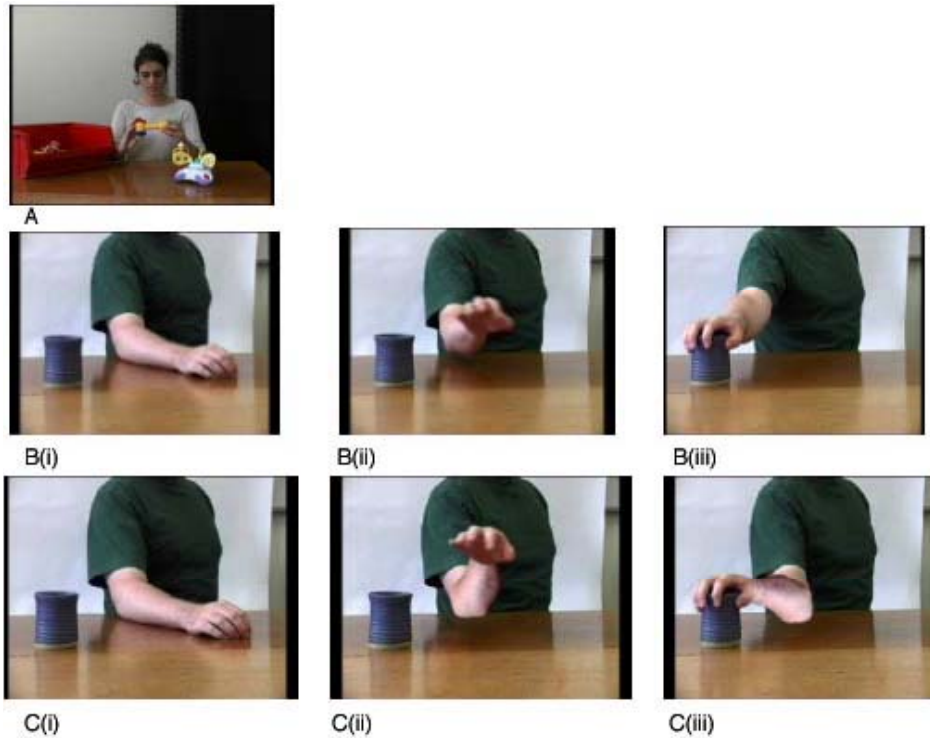
20 infants (12 females) acted as participants, with an average age of 8.0 months, or 236 days  $\pm$  8 days. All infants were born full term (37 weeks to 41 weeks) and were in the normal range for birthweight ( $>2500$ gms). Another 7 infants were tested but were excluded from the final sample as a result of excessive fussiness during the looking time component of the study.

#### *Stimuli*

A video of a male human torso with one arm reaching for and grasping an object was created. This was digitally encoded and processed into still frames at 25 frames per second. A duplicate of this film was modified in Photoshop so that the elbow movement was arrested and the arm and hand moved towards the object via an impossible axis. To adults, this modified film clearly represented limb movement that was biologically impossible (see Figure 1).

One familiarisation trial consisting of a looped 8-second video clip was presented before the test trials. This familiarisation trial featured an actress seated at a table reaching for, grasping and examining a toy and then replacing the toy on the table. The two test video clips (possible and impossible action) were then presented intermixed in a pseudo—random order. The test video clips were also looped, but contained a one second gap between the end of the clip and its next

repetition. Stimuli were presented at full screen size on a 21” monitor. The viewing distance was 80cm, creating an overall stimuli visual angle of 28°.



**Figure 1.** Still frames from Films (A) Familiarisation, (B) (i-iii) Possible (C) (i-iii) Impossible.

### *Procedure*

This study was conducted in England. Each infant participated in two experimental phases: Phase 1: Measurement of infant looking times towards stimuli of possible and impossible body movement, and Phase 2: Filmed session of mother-infant interaction.

#### Phase 1: Looking Times

Each infant included in the final sample was required to meet a minimum looking time criteria of at least ten seconds with four of those seconds occurring consecutively to all of the looped stimuli. This criterion was set to ensure that infants viewed the majority of at least one complete action sequence for each condition. Once this minimum consecutive looking criteria was reached, if the infant looked away from the screen for one second or more, the next condition was presented. To reorient to the screen at the beginning of each condition, a recording of piano music was played.

Each infant was tested individually in a soundproof room, seated in the parent's lap. The experimenter monitored by video camera the infant's looking time online throughout the test session from an experimental control room adjacent to the test room. To assess the effectiveness of the online coding, 7 infants from the final sample were coded offline, and comparisons were made between online and offline scores in each condition. Intra-rater reliability was high, with Pearson correlations yielding scores of .97 for possible and .93 for impossible actions, respectively.

#### Phase 2: Mother-Infant Interaction

Following the looking time component of the study, mother and infant interaction was observed in another room. A colorful mat (2X3 m) was placed on the floor in order to create a psychological boundary for play. A variety of toys and magazines were placed on a nearby table. The toys consisted of items that were of potential interest to the mother and infant and which infants could manipulate. Mothers were told that every infant was different and that we were interested in understanding how infants play. Mothers were not instructed further than this basic information. The experimenter recorded this semi-structured play session with a digital video camera, placed on a tripod approximately 5-metres from the play area. During filming, the experimenter avoided maternal eye contact and interacted with her on a minimal basis. Filming lasted five minutes. Five measures were taken from this session. Two were related to maternal motionese behavior and three were related to infant motor behavior.

#### Maternal Measures

##### *Measure One: Level of Motionese*

For the purposes of this study, we defined motionese as a deliberate enhancing of action during object manipulation in order to afford infants greater understanding of (1) the action involved in the object manipulation and (2) the object itself. A scale developed by Brand et al. (2002) was employed to measure modifications in mother's infant-directed action, though one component was not coded (proximity). The scale assessed *interactiveness, enthusiasm, range of motion, repetition, simplification of action, punctuation* and *rate of presentation*. Three additional behaviors were scored: *Mother related toy presentations* assess the frequency of changes in maternal agenda, such as changing the toys due to her own attention span. *Infant related toy presentations* assess whether the mother or infant change the toys available to the infant due to the desires of the infant. For example, the toys are not changed as the infant is happy interacting with one toy or the toys are constantly changed due to the infant displaying a lack of interest in each toy. This measure is thus a measure of infant temperament and a measure of maternal sensitivity to the infant. Finally, *Simplification of environment* assessed the awareness of the mother to elements in the play area that may distract her infant from the toy that was the focus of mother and infant attention. For example, the mother may simplify the environment of the infant by removing all toys near the infant that were not being examined.

All measures were based on 5-point ratings reflecting behavior observed across the entire 5-minute period, with zero representing low frequency/intensity and four representing high frequency/intensity. A single, composite measure of *level of motionese* was created by summing the eleven individual scores; this composite score could range from 0-44.

#### *Measure Two: Time Spent Performing Motionese*

A second measure of motionese was taken that assesses the five-minute session in terms of the presence/absence (0/1) of motionese movement. This measure indexed the amount of time that the mother is involved in performing motionese - style actions. The five-minute session (300 seconds) was subdivided into 30 epochs of 10-seconds and an assessment of maternal action in each epoch was made. If any indicator of motionese was observed within a 10-second period, that epoch was scored as positive motionese time. Five indicators of motionese were formulated, four of which required maternal actions that were made with a toy. These indicators were:

1. Simplification of environment: The mother simplifies the environment by removing all toys that are not being examined/interacted with, i.e. the toys near the infant are removed.  
Or if the mother is performing actions with a toy:
2. Range of motion: The mother has very broad, expansive and/or exaggerated movements when presenting toys to the infant.
3. Punctuation: The mother has sharp, abrupt, very punctuated actions when manipulating/demonstrating the toy; mechanical.
4. Mother simplification action: The mother displays small, simple units of actions when manipulating the toy at any one time.
5. Repetitiveness: The mother is repetitive with movements when she presents the toy to the infant.

To gain one measure of motionese for each mother, the motionese positive epochs were summed to form an overall score. There was therefore a potential score range from 0 to 30. This final score was labelled *time spent performing motionese*.

#### *Infant Measures*

Each 10-second epoch was scored for the presence/absence (0/1) of specific aspects of infant fine, gross and overall motor activity. *Fine motor activity* reflected the number of 10-second periods within the 5-minute session that the infant grasped or manipulated a toy in a semi-dextrous fashion (e.g., pressing buttons, holding objects, and twisting toys). *Gross motor activity* was scored as present when the infant used gross motor movements to interact with toys and objects (e.g., whole arm or limb movements; whole hand movements such as hitting an object or toy). Fine and gross motor scores were summed to create a further measure indicating *overall motor activity*.

### Reliability of Mother – Infant Interaction Measures

Inter-rater reliability was performed on a sample of 7 participants. Pearson correlations were high, yielding scores of .79 for *level of motionese*, .95 for *time spent performing motionese*, .88 for *fine motor activity*, .92 for *gross motor activity* and .90 for *overall motor activity*.

### Parameterizing Measures of Mother and Infant Behavior

All measures of mother and infant behavior just described were split at the median for analytic purposes, creating groups of 10 high- and 10 low-scoring individuals on each measure (except in the case of *overall motor activity* in which the low group was comprised of only 9 individuals due to the median value of the distribution).

## **RESULTS**

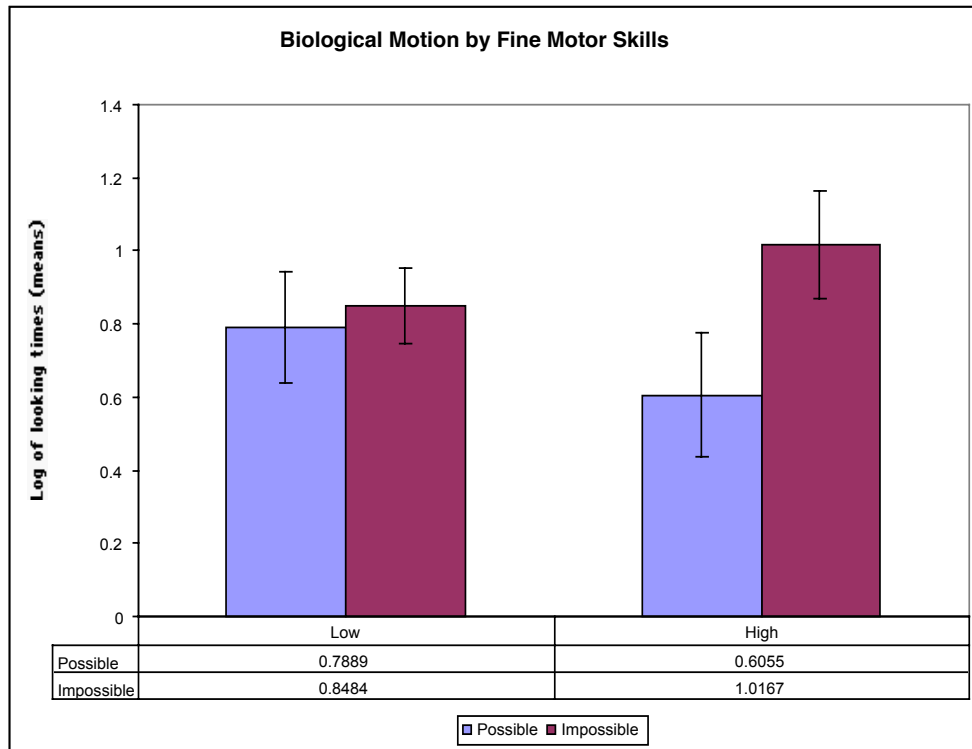
To assess infant sensitivity to the biological possibility-impossibility of observed action, a series of 2 X 2 repeated measures ANOVAs was conducted on looking time data. The possibility of actions (possible or impossible) always served as the within participants' factor, crossed with one of the following between-participant factors: level of motionese, time spent performing motionese, infant fine motor skill, infant gross motor skill and infant overall motor skill (all scored high vs. low). Due to positive skew in looking times, the log of each looking time was used for these analyses.

The ANOVAs indicated that there was an effect of possibility, with increased looking times to the impossible film. The main effect of possibility [ $F(1,19)=8.204$ ,  $p=0.01$ ], reflecting greater attention paid to impossible (Mean=0.94, SE,0.14) than possible actions (Mean=0.68, SE 0.16) was qualified by a significant interaction only in the case of infant fine motor activity [ $F(1,19)=4.58$ ,  $p < 0.05$ ]. This interaction indicated that infants with higher than median fine motor skills displayed a preference to look longer at stimuli depicting impossible body movements rather than stimuli displaying possible body movements. Infants below the median for fine motor skill did not display a preference for either possible or impossible stimuli. The interaction of possibility and fine motor skill is illustrated in Figure 2.

## **DISCUSSION**

This experiment investigated infant perception of human body movement, via the analysis of infant preferential looking measures derived from observation of stimuli displaying possible and impossible body movements. We also examined two potentially distinct factors, operationalized in a variety of ways, that could

potentially predict variation in looking times and electrophysiological responses to stimuli-- infant motor ability and maternal motionese.



**Figure 2.** Looking times to stimuli by fine motor skill groups. The effect of fine motor skill is clearly evident, with the high fine motor skill group showing an increase in looking time from the possible to the impossible film whereas the low fine motor skill group show no difference in looking times between the stimuli.

The fact that infants looked longer at the impossible than possible body movement strongly suggests that infants of eight months are, in general, capable of discriminating between these types of human body limb movements. The preference for looking at impossible action is consistent with the notion that these are regarded as more novel, if not surprising. The significant interaction between possibility of observed biological movement and infant fine motor skill indicates that infants of 8 months who possess above median fine motor skill abilities process perceptual information relating to biomechanical motion differently, with greater looking at impossible stimuli than infants from below the median in fine motor skill abilities. Indeed, this result suggests that it is only those infants with high fine motor skill that discriminate between the possible and impossible stimuli (see Figure 2). This finding gives support to the notion that the infant's own motor

capabilities relate to their understanding of the human body. As such, fine motor skills appear to determine infant discrimination of possible and impossible human biological movements.

No interaction was found between infant looking times and maternal motionese. In order to ensure that this null result was not an artefact of assessing motionese via composite measures of distinct aspects of motionese, we decomposed the composite of the variable *level of motionese* into individual components of motionese. We assessed this data in the same manner as the other between-subjects measures conducted in Experiment One. These analyses also did not produce an interaction between infant looking times and maternal motionese. This study therefore provides no support for the hypothesis that exposure to varying levels of maternal motionese contributes to accounting for variation in infant discrimination of the possible and impossible body movements. Potentially the observation of normal body movements provides sufficient experiences to allow infants an understanding of the biological limitations of human movement. This hypothesis implies that the observation of motionese is not required for typical infant development.

The results of this study suggest an association between the infant's own ability to perform fine motor actions and visual perceptual abilities relating to the observation of human movement. One hypothesis that may explain these results is that the ability to perform detailed and specific movements provides the experience necessary to discriminate possible from impossible actions. An alternative is that the perception of biomechanical action serves as the basis for the development of fine motor skills. The disambiguation of these hypotheses, however, is not the focus of this article, although it is undoubtedly an area for further research.

The main effect of possibility in the present study, with increased looking at the impossible stimuli, conforms to the results of previous research. Discrimination of possible and impossible point-light display motion has been shown in infants as young as 5 months (Bertenthal et al., 1987). The finding that fine motor abilities may determine infant discrimination of possible and impossible human biological movements has not been previously demonstrated. A strong conclusion on the relationship between infant perception of action and infant fine motor skill can only be tentative, for this interaction requires replication.

The assessment of infant electrophysiological responses to possible and impossible biological motion may enable clarification of the results found in Experiment One. It should be noted that the examination of neural substrates related to the perception of biological motion is an important investigation in its own right. In Experiment Two we investigate the neural substrates associated with the perception of human movement. As outlined previously, bursts of Gamma frequency EEG have been associated with the perception of possible human motion in adults. Therefore, in this experiment we measured EEG while infants passively viewed stimuli of possible and impossible movements. Consistent with Experiment One, we also collected data from mother-infant interaction in order to determine

whether variation in infant motor skill or maternal motionese covaried with differences found between participants in measures of Gamma frequency activity.

## EXPERIMENT TWO

### METHOD

#### *Participants*

16 infants (8 females and 8 males) participated, with an average age of 8.0 months, (243 days) with a range from 235-254 days. All infants were born full term (37 weeks to 41 weeks), were in the normal range for birthweight (>2500gms), and were recruited from the London area. Another 11 infants were tested but were excluded from the final sample as a result of excessive fussiness (n=2), failing to reach the minimum requirements for adequate averaging of the EEG data (n=8), or computer software failures (n=1). These infants had not previously seen the experimental stimuli and did not participate in Experiment One.

#### *Procedure*

Each infant participated in two test phases that were always conducted in the same order: (a) Phase 1: EEG, and (b) Phase 2: Filmed session of mother-infant interaction.

#### Phase 1: Electroencephalography

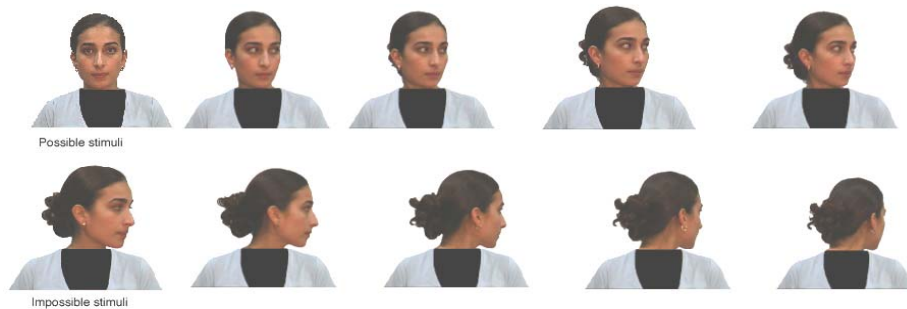
There was no fixation stimulus in order that artefacts associated with the presentation of such a stimulus would not contaminate the gamma frequency in the epoch of interest. Rather, 800ms of a black screen was presented to each subject prior to the presentation of the stimuli. The two conditions were presented to the infant in a random order with the constraint that the same condition was not presented three times consecutively and that the number of presentations of each set of stimuli was balanced in every 20 films presented. A train noise was present throughout each trial in order to orient the infant to the screen. The sound started anew with each trial, and was selected to be not interpretable as biological in nature or time-locked to any specific part of a video sequence.

The same procedures that were employed during the assessment of looking times in Experiment One were used in the present experiment, with the following exceptions. If the infant became fussy or uninterested in the stimuli, the experimenter gave the infant a short break. The session ended when the infant's attention could no longer be attracted to the screen. EEG was recorded continuously and the infants were also video-recorded throughout the session.

#### *Stimuli*

Two pairs of stimulus sequences were used. In each pair one sequence was biologically possible and the other was not. The first pair of stimuli comprised the stimuli used in Experiment One. The other pair comprised new "motion-possible" and "motion-impossible" stimuli. In the former, a female turned her head to its biologically possible extent and in the latter the head was turned in the same

manner but to an impossible degree (see Figure 3). To adults, the new impossible stimuli clearly represented motion that was not biologically possible. Stimuli were presented on a 21" monitor with a viewing distance of 80cm, creating an overall visual angle of 19°.



**Figure 3.** Still-frames from the sequences presented to infants. Note that the impossible sequence presented the possible head movement first, then proceeded to the impossible motion.

#### *EEG Recordings and Analysis*

EEG was recorded continuously from 62 channels referenced to the vertex (Tucker, 1993) throughout stimulus presentation. A ground electrode was positioned at the rear of the head, and electrooculogram was recorded from electrodes positioned above both eyes and on the outer canthi. All bioelectrical signals were recorded using Electrical Geodesics Inc. amplifiers (Eugene, OR) with an input impedance of 100 Mohms. Sampling rate was 250 Hz (every 4 ms), band pass was 0.1 to 100 Hz, and gain was set to 10,000 times. A time-frequency analysis of the data was performed using a continuous wavelet transform. The detailed methods used for recording and time-frequency analysis of EEG are described in Csibra, Davis, Spratling and Johnson, (2000) and Johnson et al. (2001).

#### *Data Reduction*

The epoch of interest was defined as beginning 100ms before the point in the stimuli sequence when the possible and impossible stimuli diverged. Therefore, at the onset of the epoch the arm was lifting slightly, or the head turning, as it would be for possible movement. This first 100ms of the epoch was used as a baseline period as it was identical between the motion-possible and motion-impossible arm movement sequence. Due to the greater extent of head turning in the motion-impossible condition, for this condition we selected a baseline period matched for the extent of head turning.

For each trial, EEG data was truncated to create an epoch from 200ms before the difference between films began to 800ms after the motion-possible and

motion-impossible films had diverged. After all data editing occurred, 100ms was cut from both ends of the epoch to exclude an artefact associated with the Morlet wavelet, thereby producing a final data length of 100ms baseline and 700ms after condition divergence. Data were visually edited for artefacts offline. For each individual, if the total number of trials of data for each condition came to less than 10 trials, that individual was discarded from further analyses. Missing data from individual electrodes was interpolated, using spherical spline interpolation, provided that the interpolation did not exceed 10 percent of data gained from a single trial (six electrodes from the 62 channel sensor net). Finally the data were referenced to the average before being transformed using the Morlet wavelet to investigate the EEG frequency 21 to 60Hz.

For each participant, a frequency plot was computed based on the difference between the motion-impossible condition and the motion-possible condition (with the former subtracted from the latter so that positive values reflected greater activation in the motion-possible condition whereas negative values reflected greater activation in the motion-impossible condition). Since we were interested in the difference between the processing of possible and impossible human movement, the production of a difference file allows for a clear comparison of processing between the two conditions. T-tests were performed on the resulting data to assess the difference between conditions in the epoch of interest. Further, participants were also divided into two groups based upon fine motor skill and other between-subject measures as described in Experiment One. These groups were analysed in the same manner as the whole sample with difference files computed and assessed.

Left and right frontal regions were assessed within 200-270ms. This epoch has previously generated results in gamma frequency studies investigating infant cognitive processes (Csibra et al., 2000; Kaufman, Csibra, & Johnson, 2003). Analysis of the data is therefore divided into two separate sections. (1) Analysis within the 212-268ms range for left and right frontal regions, and, (2) Post hoc measures of activity produced in the overall segment of EEG from other regions and latencies of interest. These post hoc measures were based on visual inspection of the time-frequency data.

For analysis of the left frontal region, the channels 7, 8, 11 12 and 14 of the geodesic sensor net (Tucker, 1993) which reside close to the channels Fp1, F3 and F7 on the ten-twenty system (Jasper, 1958) were selected as the left site of interest. The channels 2, 3, 4, 61 and 62 of the geodesic sensor net (Tucker, 1993) which reside close to the channels Fz, Fp2, Fp4, and F6 on the ten-twenty system (Jasper, 1958) were selected as the right site of interest.

#### Phase 2: Mother-Infant Interaction:

Mother-infant interaction in this experiment was assessed in the same manner as described in Experiment One. Inter-rater reliability was established from coding a sample of six subjects. Pearson correlations were high, yielding scores for

infant fine motor skill of .98; infant gross motor skill .92; maternal level of motionese .91; and maternal time spent performing motionese .97.

## RESULTS

We assessed gamma power in possible and impossible conditions by considering the difference between the two conditions. T-tests were performed a priori in frontal regions as previous research has suggested that this location may be related to infant processing of salient visual information (Csibra et al., 2000). Post hoc analysis was conducted on right fronto-temporal regions, where visual inspection indicated substantive differences between conditions.

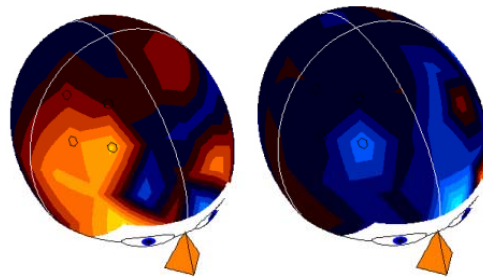
### Frontal activity

No difference in gamma power was observed between conditions in left or right frontal regions during the epoch 212-268ms. Further, no effects emerged when the participant sample was divided according to the mother-infant interaction measures of infant fine motor skill, infant gross motor skill, time spent performing motionese or level of motionese.

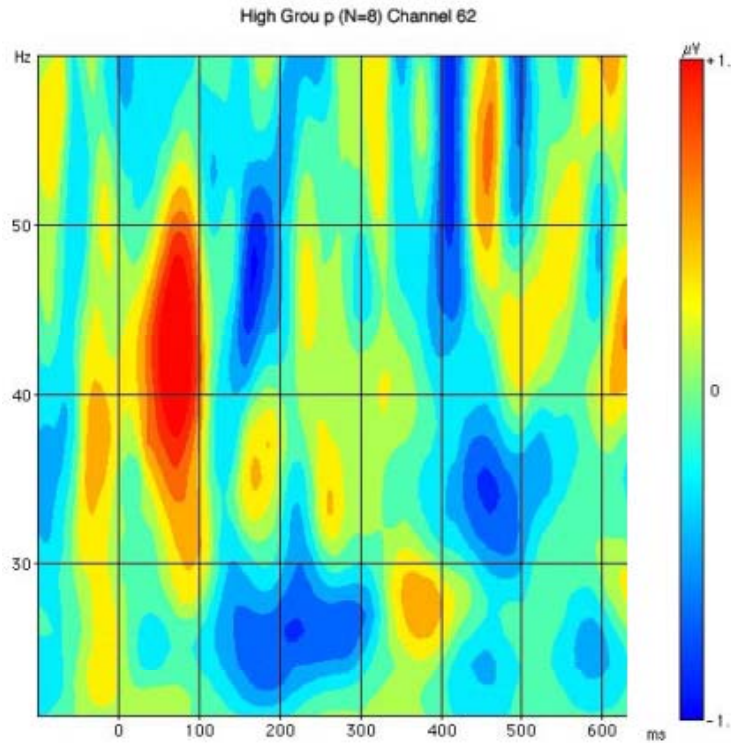
### Post hoc tests

Visual inspection of the time-frequency data suggested right fronto-temporal differences in gamma power between conditions in the timeframe 84-136ms. The channels 53, 57, 58, and 62 of the geodesic sensor net (Tucker, 1993) which reside near the channels F4 and C4 on the ten-twenty system (Jasper, 1958) were selected for analysis. No other scalp location appeared to elicit sustained differences over a cluster of channels.

Of four comparisons, only one showed a difference as a function of what was observed during mother-infant interaction: Infants who scored higher on measures of fine motor skill manifested a positive burst of gamma, indicating greater activation in the motion possible condition relative to the motion impossible condition (N=8) [ $t=-2.625$ ,  $p=0.034$ ]. This can be seen in Figure 4 topographically as a red area across right fronto-temporal sites. Figure 5 displays time-frequency properties from one channel in the right fronto-temporal region, whereby the significant difference between conditions from 84-136ms is clearly indicated in red within that timeframe from approximately 30 to 50Hz.



**Figure 4.** Topographical difference map displaying gamma frequency activity across right fronto-temporal channels at 88ms (left) and 136ms (right) for high fine motor group infants (n=8). Blue indicates greater gamma activity in impossible, red indicates greater power in possible condition. Those channels selected for statistical analysis are highlighted.



**Figure 5.** High fine motor group. Time-frequency (20-60Hz) difference plot (possible subtract impossible) of a single channel (Channel 62), which is broadly representative of gamma activity in the epoch of interest for the channel group.

## DISCUSSION

These experiments investigated individual differences in the development of the ability to perceive human action. We examined the environment provided by mothers (as indexed by maternal motionese) and infant motor abilities. We also investigated infants processing of biological movement as indexed by looking times and gamma-band time-frequency analysis of EEG. Experiment One indicated that infants at 8 months were capable of discriminating possible from impossible stimuli. An interaction was also found between infants with relatively high fine motor skill looking longer towards stimuli depicting impossible biological motion when compared to their looking towards possible biological motion. Experiment Two investigated infant neural activity in the gamma frequency during exposure to stimuli depicting possible and impossible biological motion.

In Experiment Two, the only consistent Gamma EEG effect observed was in the period from 86-136ms for the sub-group of infants with relatively high fine motor abilities. In concordance with the looking time results in Experiment One, the low fine motor group did not show neural evidence of discriminating between the stimuli. This result strengthens the association between the infants' own ability to perform fine motor actions and their perception of human movement. One possibility not examined in this article is that there is no causal relation between these abilities, but that they both correlate independently with the general developmental stage of the infant. In other words, infants that are more generally developed do better at both the perception and production of biological motion. This is clearly an issue for further research.

The latency of the difference in gamma power between conditions that is seen in Experiment Two can be interpreted in relation to previous behavioral studies with children and adults. In these studies, the identification of human movement occurs exceptionally rapidly. For example, Johansson (1973) reported that when naïve adults were presented with a point light display (PLD) for 200ms, they reported the perception of a walking human. Indeed, in a study comparing typical and atypical samples of children and adolescents, when presented with 120ms of a PLD, more than half the subjects identified human from object movement (Moore, Hobson & Anderson, 1995). This was despite the sequence of presented stimuli corresponding to only *three* frames presented at 25 frames per second. It is therefore reasonable to assume that neurophysiological differences between possible and impossible action should be seen in the infant brain at this time and that the increase in gamma band activity seen in the present study are related to the identification of differences seen between possible and impossible stimuli.

There were no significant results in these experiments for any variable associated with motionese or for gross motor skill. There are a number of possible reasons for this lack of any relationship between motionese or gross motor skill and infant perception of biological motion at a behavioral or neural level. For the motionese measures, perhaps the most logical explanation is that they do not index infant's perceptual experience of action. Alternatively, motionese does correlate with infant's perceptual experience of human action, but this does not have an effect on the development of their perceptual skills. By this view, a surprising hypothesis raised by these results is that within the normal range, motor experience or skill is a more important predictor of infant visual perceptual abilities than is their visual experience.

The results of Experiment Two relate well to adult research, where it has been shown that increases in gamma activity in fronto-central and parietal sites correlate with the recognition of postural instability (Slobounov et al., 2000). It was also found that the change from baseline was higher in the right hemisphere in the 30-50Hz frequencies. Even though the present study analysed difference plots of time frequency data rather than comparing the two conditions to baseline, those differences that were seen in the present study were also in fronto- temporal

regions of the right hemisphere. The interpretation by Slobounov et al. (2000) of their results was that during visual recognition tasks, perceptual thresholds exist that cue relevant information. The result of the present study suggests that these perceptual thresholds develop during, or prior to, the first postnatal year.

It must be recalled that the gamma difference seen between relative high and low fine motor ability is indicative of differences that were also seen between groups in the behavioral domain in Experiment One. This raises the issue of whether measures of motor development in this study are actually of general developmental advancement across all domains. Further studies throughout infancy are required to determine the nature of interactions between motor development, general development and visual perception.

In summary, the results of this study demonstrate that individual differences in infant fine motor skill as measured during a period of mother-infant play are related to infants' behavioral and neural responses to biologically possible and impossible human movement.

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