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The neural basis of non-verbal communication – enhanced processing of perceived give-me gestures in 9-month-old girls

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Abstract

This study investigated the neural basis of non-verbal communication. Event-related potentials were recorded while twenty-nine 9-month-old infants were presented with a give-me gesture (experimental condition) and the same hand shape but rotated 90 degrees, resulting in a non-communicative hand configuration (control condition). We found different responses in amplitude between the two conditions, captured in the P400 ERP component. Moreover, the size of this effect was modulated by participants' sex, with girls generally demonstrating a larger relative difference between the two conditions than boys.

Keywords: give-me gesture, ERP, P400, sex differences, non-verbal communication, social perception, infancy

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Gestures may be used as social tools for expressing one's own feelings and thoughts, cooperating with others, and drawing others' attention to objects and events (Carpendale & Carpendale, 2010; Tomasello, Carpenter, & Liszkowski, 2007). In early childhood gestures can be expressed in grimaces and smiles (Caselli, 1990) and are later exhibited with fingers, hands, and arms (Crais, Douglas, & Campbell, 2004). By the end of the first year of life, gestures such as giving (Caselli, 1990; Mundy, Sigman, Ungerer, & Sherman, 1986) or pointing (Bates, Camaioni, & Volterra, 1975; Tomasello, 2008) become meaningful for expressing goals and communicating with others.

Research exploring the development of the pointing gesture is quite prevalent (e.g. Butterworth, 2003; Camaioni, Perucchini, Bellagamba, & Colonnesi, 2004; Daum, Ulber, & Gredebäck, 2013; Tomasello, Carpenter, & Liszkowski, 2007; von Hofsten, Dahlström, & Fredriksson, 2005). In contrast, the give-me gesture (a face-up palm directed toward the observer; Mundy et al., 1986) has received little attention. We believe that the give-me gesture warrants more interest from the scientific community considering its communicative importance in serving multiple functions, such as referring to a specific object, expressing a request and communicating an action goal (Shwe & Markman, 1997).

From a behavioural perspective, we know that children begin to give and request objects to and from others at around 9 to 12-months of age (Bates et al., 1975;

Carpenter, Nagel, & Tomasello, 1998; Crais et al., 2004; Masur, 1983). A recent eye tracking study suggests that infants show sensitivity to the communicative properties of give-me gestures by 12-months of age (Elsner, Bakker, Rohlfing, & Gredebäck, 2014). In this study, infants observed a give-and-take interaction between two individuals. The authors assessed differences in latency of goal-directed gaze shifts from a hand transporting a ball to a receiving hand that formed either a give-me gesture or an inverted hand shape (hand shaped as a give-me gesture but presented upside-down). The results revealed that infants shifted their gaze significantly earlier toward the goal (the receiving hand) if it was shaped as a give-me gesture in comparison to the inverted hand shape. Additional control conditions ruled out that the effect was based on affordance, e.g. a simple match between the ball and the receiving hand, or attentional differences (Elsner et al., 2014). Jointly, the results indicate that infants are sensitive to the communicative intent of a hand shaped in a give-me gesture.

Further, Thorgrimsson, Fawcett, and Liszkowski (2014) demonstrated that 14-months-old infants have a clear expectation of adequate responses to the give-me gesture. That is, when observing an interaction between two people, infants anticipate that an object will be passed to another person when the give-me gesture request is presented, suggesting again that infants at this age can recognize the communicative intent of the gesture (Thorgrimsson et al., 2014).

Interestingly, the perception of give-me gestures may be different for typically developing children than children with Autism Spectrum Disorder (ASD). In a recent study, 5- to 6-year-old children with ASD were found to look differently at social interactions incorporating give-me gestures than typically developing children (Falck-Ytter, von Hofsten, Gillberg, & Fernell, 2013). This may suggest that children with this clinical diagnosis might be less able to read the meaning of the give-me gesture or that they are less interested in people's reactions confronted with give-me gestures (Falck-Ytter et al., 2013).

Motivated by eye tracking studies that highlight the importance of the give-me gesture as a tool for goal understanding and encoding social interactions (Elsner et al. 2014; Falck-Ytter et al., 2013; Thorgrimsson et al., 2014), the current study investigated the neural activation that is evoked when observing give-me gestures.

To our knowledge, only two studies have investigated the neural correlates of gesture perception early in development. The first study investigated the neurodevelopment of pointing perception (Gredebäck, Melinder, & Daum, 2010), whereas the second assessed the perception of grasping gestures (Bakker, Daum, Handl, & Gredebäck, 2014). In those studies, the authors reported the ERP component P400 to be sensitive to the congruency of pointing or grasping, revealing higher mean amplitudes for the congruent (gestures directed toward an object) compared to the incongruent condition (gestures directed away from an object). Here, we aim to explore if the same ERP component generalizes over communicative settings, from hand configurations directed toward objects (pointing; Gredebäck, et al., 2010, and grasping; Bakker et al., 2014) to more socially oriented gestures, in this case the give-me gesture. If the same underlying neural processes are involved in processing a large array of gestures, than we would expect larger amplitudes of the P400 for the give-me gesture than a hand configuration that is perceptually very similar but has no communicative intent (from here labelled as non-communicative hand configuration).

In addition, we aim to investigate the relation between infants' neural response to the give-me gesture and infants' own ability to respond to the same gesture on a behavioral level. Prior work has demonstrated that infants process both pointing (Gredebäck, et al., 2010) and grasping gestures (Bakker et al., 2014) by 9 months of age. At the same age, infants also start to engage in producing give-me gestures (Bates et al., 1975; Carpenter et al., 1998; Crais et al., 2004; Masur, 1983). Based on the revealed correspondence between infants' neural potentials and behavior in prior EEG studies (i.e. Bakker et al., 2014), the current study targets both 9-month-olds' neural correlates of the give-me gesture and their behavioral responses to give-me requests (Responding to Behavioral Request procedure from the Early Social Communication Scales; Mundy et al., 2003). We expect that behavioral responses to the give-me gesture will correspond with P400 amplitudes. That is, relative amplitudes (give-me gesture vs. non-communicative hand configuration) should be higher in infants that are proficient in responding behaviorally to the give-me gesture.

Further analyses in this study explored individual differences in gesture perception with respect to infants' sex. Based on prior studies revealing that girls are ahead of boys in the onset of gesture and language production (Butterworth & Morisette, 1996; Özçalışkan & Goldin-Meadow, 2010), it is possible that girls are more proficient in discriminating between the give-me gesture and the non-communicative hand configuration than boys. If we find such an effect we would expect an interaction effect between sex and condition. That is, both boys and girls should be able to differentiate between the two conditions, but we would expect the effect to be bigger in girls than boys.

In summary, the current study has three aims: to investigate the perception of give-me gestures on a neural level, to investigate infants' behavioral response to the give-me gesture and to investigate the presence of sex differences in social perception mechanisms.

Methods

Participants

The final sample consisted of twenty-nine 9-month-olds (15 girls, mean age 8 months and 28 days, *SD* = 6 days). An additional 30 infants (16 girls) participated but were excluded due to fussiness (less than 10 artifact-free trials, *n* = 25) or technical problems (*n* = 5). Parents completed informed consent prior to participation and received a gift voucher of approximately 10€ for participating. The study was conducted in accordance with the standards specified in the 1964 Declaration of Helsinki and approved by the local ethics committee.

EEG Stimuli

Both the give-me gesture (experimental condition) and the non-communicative hand configuration (control condition) were presented to the infants. In both conditions the stimulus consisted of a hand (palm facing upwards in the experimental condition and the same hand rotated 90 degrees in the control condition). Stimuli were presented at random (with the constrains of maximum 3 repetitions of the same stimulus) and presented in the middle of a gray background for 1000 ms. Between each stimulus a fixation cross was presented for 100-300 ms at random (see Figure 1). Infants viewed the stimuli (20.7 x 16.5 visual degrees) on a 17-inch computer monitor at a viewing distance of 60 cm. The size of the hand was 5 horizontal and 16 vertical visual degrees. The stimuli were presented using the E-Prime 2.0, E-Studio software (Psychology Software Tools, Inc., Pittsburgh, PA, USA).

Behavioral task

First, parents were asked if they have observed their child producing or responding to the give-me gesture outside of the laboratory. Subsequently, a researcher assessed infant's behavioral response to the give-me gesture using the Responding to Behavioural Request procedure from the ESCS (Mundy et al., 2003). The experimenter first presented three rubber toys (3x3 cm) and familiarized the infant with them for approximately 60 seconds. Consequently, as soon as the infant reached for any of the objects, the experimenter requested it and waited (3 seconds) for the infant to give the toy back spontaneously. If the infant did not pass the toy, the experimenter verbally requested the toy with the phrase: "give it to me". If after 3 seconds the infant did not respond to the verbal request, the experimenter used a combination of verbal request together with a non-verbal give-me gesture. The experimenter's gesture stopped within reach of the infant. The infant's behavior was video recorded and later assessed for the frequency of appropriate responses, that is, the number of times the child gave a toy to the experimenter at the request (verbal or verbal in combination with the give-me gesture). A maximum of 3 points could be obtained. The total duration of this test did not exceed five minutes.

Procedure

During the lab visit, we first recorded infants' neural responses to the give-me gesture, followed by the behavioral task that measured the overt ability to respond to the give-me gesture. During both the EEG recording as well as the behavioural task, infants sat on their parent's lap. For the ERP task, the experimenter sat at a control computer separated from the parent and infant by a curtain and monitored the infant's behavior via a live camera. The researcher paused the experiment if the infant became inattentive and fussy. The stimulus monitor remained black for the duration of the pause. The experimenter terminated the study when the infant was no longer interested in the stimuli. The whole recording session did not exceed 10 min. After the EEG recording the parent and infant were given an approximate 5 minutes break before proceeding with the behavioral response task. This paper reports data from an ongoing longitudinal project looking at the neural correlates of social cognition and later language development.

EEG recording and analysis

We used 128-channel HydroCel Geodesics Sensor Nets to record infants' EEG. The recorded signal (250 Hz, vertex referenced) was amplified by an EGI Net Amps 300 amplifier (Electric Geodesic, Eugene, OR) and stored for off-line analysis. The EEG signal was digitally filtered (0.3-30 Hz) and segmented from 200 ms prior to the appearance of the hand to 1000 ms after the onset of the stimulus. Off-line inspection of video recordings ensured that only trials in which infants paid attention were further processed. The data was manually edited for artifacts (standard procedure for infant ERP studies, see Hoehl & Wahl, 2012). Trials with excessive noise levels (mostly due to movement artifacts) were rejected. Channels with moderate noise levels were reconstructed from an interpolation (creating an average of surrounding channels). All included trials contained no more than 10% interpolated channels. The inclusion criterion for the final analysis was at least 10 artifact free trials per condition (standard inclusion criterion for infants ERP studies, see DeBoer, Scott, & Nelson, 2007; Stets, 2012). On average, an infant saw 90 trials across both conditions, with 44 trials for the give-me gesture condition and 46 for the control hand. We baseline corrected and re-referenced (average reference) all artifact free trials in order to create average waveforms for each participant. Grand average was created from individual averages of the participants who had a minimum of 10 artifact free trials. After visual data inspection and manual data editing, a mean of 15 artifact free trials remained (range: 10 - 31) for the give-me gesture condition and a mean of 17 trials (range: 10 - 32) for the control hand. Based on the visual inspection of the individual averages and grand averages we selected 11 channels in the posterior area (62, 67, 70 71, 72, 74, 75, 76, 77, 82, 83) for statistical analyses. We captured three components in the ERP wave morphology after the stimulus onset, and performed the analysis on the mean amplitude in the following three time windows (see Figure 2): P1 (80 - 140 ms), N200 (150 - 250 ms) and P400 (300 - 600 ms). We conducted analyses of variance (ANOVAs) to compare the mean amplitudes between conditions (the give-me gesture and control) in all ERP components (P1, N200, P400) and to assess the effect of sex on ERP amplitude differences, respectively.

Results

ERPs

Our first ERP analysis focused on the component of interest, the P400. In order to test the possible difference between the conditions as well as the effect of sex on the modulation of the P400 amplitude, we conducted a 2 (Sex) x 2 (Condition) mixed repeated measures ANOVA. Results revealed a main effect of Condition $F(1,27) = 40.12$, $p < .001$, $\eta^2 = .598$, with a mean amplitude of 15 μV (*SD* = 6 μV) in response to the give-me gesture and 9 μV (*SD* = 7 μV) in response to seeing the non-communicative hand configuration. Overall, 26 out of 29 infants demonstrated larger amplitudes for the give-me gesture compared to the non-communicative hand configuration. Additionally, there was a significant interaction between Condition and Sex ($F(1,27) = 5.384$, $p = .028$, $\eta^2 = .166$; see Figure 3). To inspect the Condition by Sex interaction, we performed planned comparison paired-samples *t*-tests (separately for each sex). Results revealed significant differences between conditions, both for girls ($t(27) = 4.750$, $p < .001$) as well as for boys ($t(27) = 4.360$, $p < .001$) with a more positive mean amplitude for the give-me gesture. As both boys and girls displayed a significant difference in their response to the two gestures, and as the direction of the difference was similar, it is possible that the interaction between Sex and Condition stems from differences in the size of the effect. To test this prediction, we further examined the difference between sexes in their conditional amplitude difference scores. We calculated the amplitude difference score by subtracting the mean amplitude in the control condition from the give-me gesture condition for each infant individually. Subsequently, we performed an independent-samples *t*-test with amplitude difference as the dependent variable and sex as the grouping variable. The analysis revealed a significant amplitude difference between sexes ($t(27) = 2.320$, $p = .028$). This shows that the interaction is driven by the size of the difference between the conditions that is larger for girls (girls: $M = 8\mu V$, $SD = 6.3\mu V$; boys: $M = 3.7\mu V$, $SD = 3.3\mu V$). It is, however, also possible that the interaction effect is influenced by girls' lower mean amplitudes in the control condition.

To ensure that the effect between conditions as well as the interaction between Condition and Sex is specific to the P400 we performed follow-up analyses for two other components visible in the ERP wave morphology, i.e. P1 and N200. We performed 2 x 2 mixed repeated measures ANOVAs with Condition as a within-subject factor and Sex as between-subject factor on the mean amplitudes of the P1 and N200. The analysis for the P1 component revealed no significant effects, neither for differences between conditions ($F(1,27) = 2.297$, $p = .141$, $\eta^2 = .078$) nor for an interaction between Condition and Sex ($F(1,27) = 2.149$, $p = .154$, $\eta^2 = .074$). The analysis for the N200 also failed to show significance, neither for differences between the conditions ($F(1,27) = 2.808$, $p = .105$, $\eta^2 = .094$) nor for an interaction ($F(1,27) = .077$, $p = .783$, $\eta^2 = .003$).

Behavioral task

On a behavioral level, none of the infants responded to the give-me gesture request as assessed by the ESCS scale. Four infants responded by moving the hand with the object to the experimenter but did not release it. Two infants moved the hand away from the experimenter when seeing the request. None of the caregivers reported that their infant was able to proficiently produce or respond to the give-me gesture outside the laboratory. Therefore, no statistical analysis was performed.

Discussion

This study investigated the neural basis of infants' give-me gesture perception. As predicted, we found that infants' P400 amplitude increased when infants were presented with the give-me gesture compared to a non-communicative hand configuration. This difference was significant despite the fact that most of the infants did not demonstrate an overt sensitivity to the give-me gesture (as measured with the ESCS scale). In addition, as predicted, we demonstrated sex differences in the neural responses to the give-me gesture, with larger amplitude difference between conditions in girls than boys.

P400 - neural correlate of the give-me gesture

The give-me gesture elicits larger P400 amplitude than the non-communicative hand configuration. This effect is highly similar to the neural response elicited while observing goal-directed pointing (Gredebäck et al., 2010) and grasping

(Bakker et al., 2014). In those studies, the amplitude of the P400 was larger for typical and functional referential cues (i.e., give-me gesture, congruent pointing, congruent reaching) than for the control stimuli that were less communicative or functional. Here, we demonstrate similar differences in the amplitude of P400 for communicative gestures directed toward the infant. Together, these findings demonstrate that the P400 indexes a wide range of social gestures, comprising both gestures directed toward objects and those directed toward the observing infant.

In contrast to prior studies examining neural correlates in relation to behavioral responses to pointing and grasping, we did not find a relation between the P400 ERP to give-me gestures and infants' behavioral responses to the same gesture. In the prior study on grasping perception (Bakker et al., 2014), 5-6 months old infants' own experience with grasping was closely connected to their ability to encode the relation between the presented object and the grasping hand. More specifically, a difference in the P400 between conditions (hand directed toward or away from the object location) was only evident in infants that were able to perform functional grasping.

In the current study, however, infants that did not show a behavioral compliance to the give-me gesture showed a clear sensitivity in evoked ERPs to this gesture. It is possible that the neural correlates of basic action perception and action production develop simultaneously for actions that emerge early during infancy (like grasping). However, gestures like the give-me gesture are more complex and an appropriate behavioral response may require a deeper understanding of gestural properties and turn-taking in social interactions. Another possibility is that our results capture an early neural sensitivity that may constitute a functional prerequisite of later overt behavior. As all intentional behavior must have its neural underpinnings, it is possible that the neural support networks must first be in place in order for overt behavior to emerge. For a more immediate connection between referential gesture communication and infants' own motor abilities in the case of grasping, see Bakker at al. (2014). It is however worth mentioning that the absence of behavioral responses found in the current study is not in accordance with prior work conducted by Mundy and colleagues who used the same ESCS scale (Mundy et al., 2007). In Mundy and colleagues' study, 29% of the tested infants showed successful responses to the request. One possible explanation for the difference between Mundy et al.'s and our study could be the length of the procedure. In the current work, we used only one test (Responding to Behavioral Requests) from the whole ESCS scale whereas Mundy and colleagues used all 6 scales. A longer procedure could have had an impact on the relation between the experimenter and the infant, leading to an improved quality of social exchange. Additionally, another potential explanation could be that Mundy et al. (2007) focused more on the effect of social motivation on infants' initiation of joint attention rather than simply assessing infants' compliant reaction to the request. This possibility could be exanimated in the future research.

Additionally, more research is required to further examine the developmental trajectories of the perception and production of give-me gestures. Longitudinal designs investigating the relation between functional and behavioral aspects of give-me gesture perception could provide new perspectives on the development of non-verbal communication and infants' understanding of cooperative actions. Additionally, it would be valuable to gain an understanding on whether the give-me gesture relates to other referential gestures and referential cues on both a behavioral and neural level. The combination of neural and behavioral measures would expand our knowledge about infants' early communicative development, which so far has been limited to pointing, even though infants' gestural repertoire is more extensive.

Individual differences in perception of give-me gestures

In the current study we found a significantly larger difference between conditions in P400 amplitudes for girls than for boys. This difference is interpreted as an indication that girls might be more sensitive to discriminating give-me gestures from other non-communicative hand configurations. To our knowledge there are no prior EEG studies that evaluated sex differences in social perception in infancy. The current study may therefore suggest that neural responses can be used as a proper measure to capture the individual differences early in development. Some sex differences, however, have been observed in infant studies that used behavioral measures. For instance, differences between boys and girls have been demonstrated in the frequency of eye contact between the child and the mother, with girls making more eye contact than boys (Lutchmaya, Baron-Cohen, & Raggatt, 2002). It has also been suggested that infant girls may be more attracted to social stimuli than boys, for example when being presented with faces (Lutchmaya & Baron-Cohen, 2002) or abstract geometric shapes chasing each other (Frankenhuis, House, Clark Barrett, & Johnson, 2013). In a meta-analytic review of sex differences in facial expression processing in infancy, McClure (2002) reported that females outperformed males in interpreting facial expressions and other non-verbal cues. These advantages for females are visible both in infancy as well as in adulthood. A recent study that inspected brain activation during observation of biological motion revealed a difference between adult female and male participants, with females showing greater activation in brain regions that are involved in social perception (Anderson, Bolling, Schelinski, Coffman, Pelphrey, & Kaiser, 2013). The authors also found a similar trend in children (Anderson, Bolling, Schelinski, Coffman, Pelphrey, & Kaiser, 2013). Based on these findings it is likely that the sex differences found in the present study could replicate across a larger range of social perception studies examining neural processes targeting social stimuli. Furthermore, we speculate that the results from this study capture possible sex differences in the processing of non-verbal cues. This is in line with previous research that reported females being more accurate in decoding non-verbal cues (Hall, 1978), joint attention and communicative skills (Olafsen, Ronning, Kaaresen, Ulvund, Handegård, & Dahl, 2006). Additionally, Özçalışkan, and Goldin-Meadow (2010) found that the onset of gesture and sentence production emerges later in boys than girls. In this context it is important to note that the current study captures sex differences in response to non-verbal social cues at a very early age, before the onset of gesture and speech production.

Taken together, we believe that infants' higher P400 amplitude was generated by encoding of communicative intent in the give-me gestures in comparison to the non-communicative hand configuration. It is important to highlight that no differences were found in ERP component (P1) that often index pure visual differences in stimuli. Additionally, prior work has also conducted several controls that rule out affordance and visual attention as alternative explanations (Elsner et al., 2014). As a whole, the P400 literature suggests that infants from an early age perceive functional and goal-directed manual actions and gestures in a similar manner. These processes operate both during observation of manual gestures directed toward objects as well as toward the observing infant. All of these events result in larger amplitude modulation in comparison to non-goal directed or non-communicative hand configurations.

In conclusion, the current study is the first to examine neural underpinnings of the give-me gesture. Our findings contribute to the understanding of the P400 neural component suggesting an involvement in encoding social interactions and non-verbal communication. More specifically, our study shows that the P400 is sensitive to observation of the give-me gesture, with 9-month-old girls demonstrating a larger difference between conditions than 9-month-old boys.

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Figure captions

Figure 1. Stimulus for the give-me gesture condition on the left and a control hand on the right.

Figure 2. Grand-average of ERP of the posterior area (channels of interest are marked in black). Black line represents the give- me gesture condition and grey line the control hand.

Figure 3. Mean amplitude P400 separately for each condition and sex. Red and blue-dashed lines illustrate the interaction between Condition and Sex.

Figure 1.TIFF

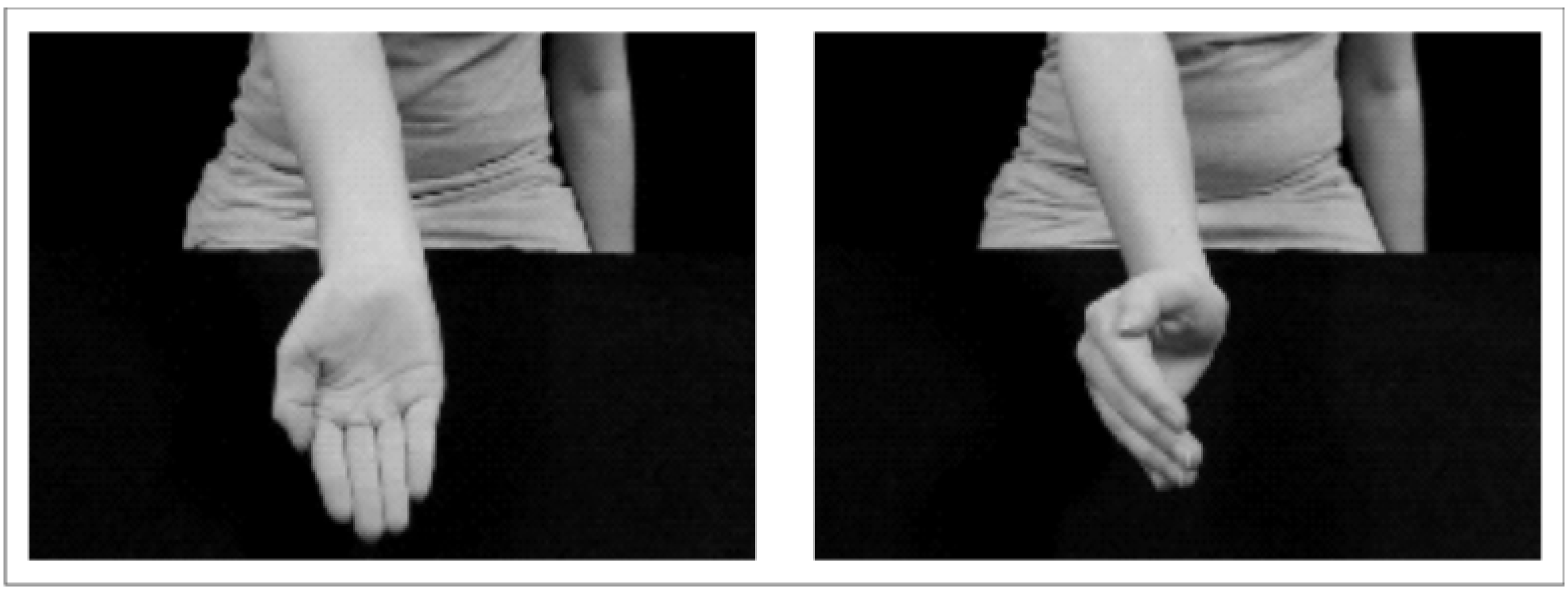

Figure 2.TIFF

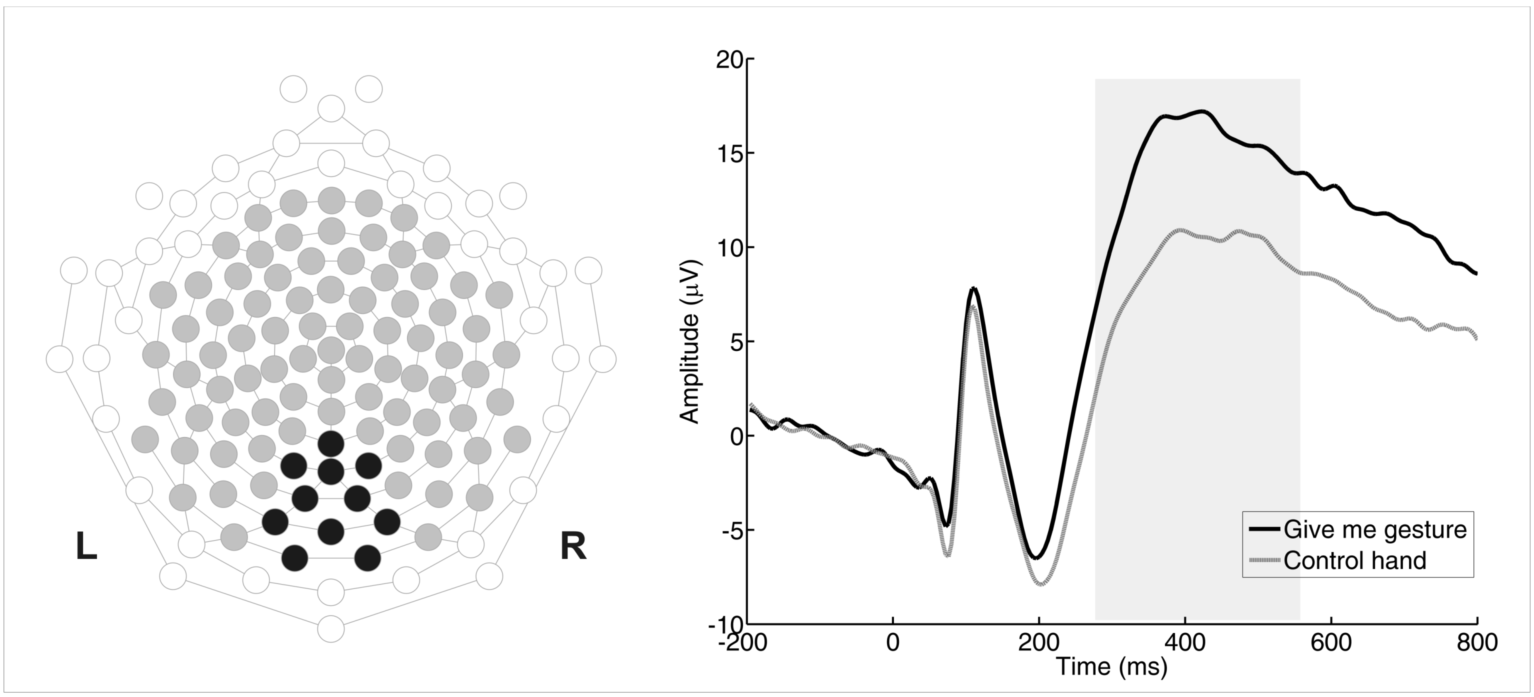

Figure 3.JPEG