Disentangling neural sources of the motor interference effect in high functioning autism: An EEG-study

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Abstract

The role of imitation in autism spectrum disorder (ASD) is controversial. Researchers have argued that deficient control of self-and other-related motor representations (self-other distinction) might explain imitation difficulties. In a recent EEG study, we showed that control of imitation relies on high-level as well as on low-level cognitive processes. Here, we aimed to further our insights into control of imitation deficits in ASD. We focused on congruency effects in the P3 (high-level), the N190 and the Readiness Potential (RP; low-level). We predicted smaller congruency effects within the P3 in the ASD group. However, we found differences in the RP but not in the P3-component. Thus, high-level self-other distinction may be preserved in ASD, while impairments are reflected during motor preparation.

Key words

Autism spectrum disorder, imitation, N190, P3, Readiness Potential, self-other distinction

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Introduction

Whether imitation is impaired in ASD is a controversial issue (Hamilton, 2013; Southgate & Hamilton, 2008). Autism spectrum disorder (ASD) is a severe developmental disorder, with social difficulties as one of its hallmark features (American Psychiatric Association, 2013). The disorder has been related to imitation deficits, assumed by some to be caused by a deficient mirror neuron system (Iacoboni & Dapretto, 2006; Oberman, Ramachandran, & Pineda, 2008; Williams, Whiten, & Singh, 2004), but also to strong imitative response tendencies. (e.g., echopraxia, echolalia, Lord et al., 2000; Spengler et al., 2010). Such 'hyperimitation' has been demonstrated in studies using so-called automatic imitation tasks such as the imitation inhibition task (Brass, Bekkering, Wohlschläger, & Prinz, 2000). In imitation inhibition paradigms, individuals react slower and make more errors when observing a movement that is incompatible to an own intended movement, as compared to when the observed and intended movement are compatible. This so-called motor interference effect is seen as a reflection of the ability to suppress externally triggered automatic imitative tendencies (i.e., motor control). While some studies have reported a *larger-than-typical* motor interference effect for individuals with ASD in imitation inhibition paradigms (e.g., Bird et al., 2007; Sowden, Koehne, Catmur, Dziobek, & Bird, 2015; Spengler et al., 2010) others have reported normal interference in this population (Gowen, Stanley, & Miall, 2008; Grecucci et al., 2013; Press, Richardson, & Bird, 2010; Sowden et al., 2015).

A compelling theory has attempted to explain increased interference effects in ASD populations, by suggesting that individuals with ASD may have problems with self-other distinction centred on motor representations (Brass, Ruby, & Spengler, 2009; Spengler et al., 2010; Spengler, Von Cramon, & Brass, 2009). The increased

motor interference effect in ASD is seen by this theory as a reflection of diminished high-level control over own and others' represented motor representations (Brass, Derrfuss, & Von Cramon, 2005; Hamilton, 2013; Southgate & Hamilton, 2008; Spengler et al., 2010, 2009). In other words, individuals with ASD may experience difficulties to disentangle own action intentions from externally triggered motor programs: they may be less able to reinforce own action intentions by indicating that externally triggered representations are *other*-related. This view has received support by fMRI studies, which reported the involvement of the temporoparietal junction (TPJ) and anterior medial frontal cortex (aMFC) of neurotypical adults within the imitation inhibition task (Brass et al., 2005; Spengler et al., 2009, 2010), areas which are core to social cognition (Saxe & Wexler, 2005). The TPJ and the MPFC are known to engage in mental state attribution and perspective taking (Van der Meer, Groenewold, Nolen, Pijnenborg, & Aleman, 2011; Zaitchik et al., 2010). In individuals with ASD, the strenght of the motor interference effect has shown a functional relationship with activity in these areas during mentalizing (Brass et al., 2009; Spengler et al., 2010). As such, the findings added to the claim that self-other distinction centered on motor processes might be disturbed in individuals with ASD (Spengler et al., 2009), an ability which may prove crucial for high-level social cognitive skills such as mental state attribution and perspective taking (Brass et al., 2009; Spengler et al., 2009).

However, several processes may underlie motor interference in automatic imitation tasks. In a recent study with neurotypical adults, we aimed to disentangle different processes underlying the motor interference effect, by submitting the imitation inhibition task to electro-encephalography (EEG; Deschrijver, Wiersema & Brass, in press). Owing to the excellent temporal resolution of this technique, we

could show that not only high level cognitive processes underlie the motor interference effect, but also low-level perceptual and motor preparation processes. More specifically, we identified congruency differences in the amplitudes of three distinct event related potentials (ERPs): First, the P3 component has proven sensitive to self-related processing and mechanisms of self-other distinction (Deschrijver, Wiersema, & Brass, 2015; 2016; in press; Holeckova, Fischer, Giard, Delpuech, & Morlet, 2006; Knyazev, 2013; Perrin et al., 2005; Sebanz, Knoblich, Prinz, & Wascher, 2006; Tacikowski, Cygan, & Nowicka, 2014; Tacikowski & Nowicka, 2010). In our study (Deschrijver, Wiersema & Brass, 2016), the parietal P3 (mostly referred to as the P3b; Polich, 2007; Volpe et al., 2007) showed larger amplitudes for congruent than for incongruent trials. This is consistent with the claim that imitation inhibition involves high-level processes related to self other distinction, as suggested by earlier fMRI studies (Brass et al., 2005; Spengler et al., 2010, 2009). Second, the N190 component, an ERP-component related to the visual processing images of the human body (Thierry et al., 2006), showed a congruency difference as well. This suggests that a participant's action intention affected early visual processing of the observed action, indicating an influence of action on perception. Third, we found a congruency-related difference in the Readiness Potential (RP; with the spatial resolution of the EEG-signal increased by means of Laplacian transformations; Rigoni et al., 2013; Tandonnet et al., 2005; Vidal et al., 2003, see also Methods). This is a component which typically magnifies with increasing complexities of motor preparation (Rigoni, Brass, Roger, Vidal, & Sartori, 2013; Tandonnet, Burle, Hasbroucq, & Vidal, 2005; Vidal, Grapperon, Bonnet, & Hasbroucq, 2003). The congruency effect in RP might reflect an influence of perception on action. In sum,

we showed at least three distinct processes might underlie the motor interference effect, of which high-level self-other distinction is just one.

In ASD, it has never been investigated whether processes other than high-level social cognitive processes are affected during imitative control. Moreover, to the best of our knowledge, imitation inhibition tasks have never been assessed in this population by means of a neuroimaging technique. In the current study, we therefore aimed to disentangle the different processes underlying automatic imitation by means of EEG, in a group of adults with high-functioning autism (HFA) and matched controls. Following up on our earlier findings (Deschrijver et al., in press), we focused on congruency effects in the P3 component, the N190 component and the RP. As a primary hypothesis, we expected that the group with HFA would show a decreased congruency effect within the P3 component, as a reflection of diminished high-level self-other distinction abilities (Deschrijver et al., 2015; 2016; in press; Spengler et al., 2010). Moreover, we wanted to investigate the role of low-level perceptual and motor preparation processes in imitative control in ASD (Deschrijver et al., in press), by evaluating N190 and RP potentials, respectively.

Methods

Participants

We recruited 23 adults with HFA by means of a recruiting announcement distributed by the Flemish Autism Association and our own research database. The 23 participants with HFA were individually matched with a neurotypical control participant (CON) on demographic measures of age (±5 years, range: 22 - 46 in both groups), gender and handedness (as measured by the Edinburgh Handedness

Inventory; Oldfield, 1971). We screened participants in the CON group (24 neurotypical individuals in total) on several exclusion criteria prior to participation (the use of psychiatric medication and neurological, psychiatric, sensory or motoric problems). Before entering the study, all participants with HFA had received a formal clinical diagnosis of ASD (including autism, Asperger's syndrome and PDD-NOS) from a multidisciplinary team and were free of any additional neurological disorder. To verify the ASD diagnosis, the Autism Diagnostic Observational Schedule (ADOS; Lord et al., 2000) Module 4 was administered by a trained researcher. In addition, all participants filled out self-report questionnaire forms: the Edinburgh Handedness Inventory (Oldfield, 1971), the AQ (Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001), and the SRS-A (Bölte, Poustka, & Constantino, 2008). All participants gave written informed consent before participation and were financially compensated for their participation. The local ethics committee approved the study.

Similar to previous studies of HFA (e.g., Deschrijver, Bardi, Wiersema, & Brass, 2015; Magnée, De Gelder, Van Engeland, & Kemner, 2008; Zwickel, White, Coniston, Senju, & Frith, 2011), we included in our main analyses HFA participants who scored above or one point below cut-off on one subscale of the ADOS and attained an ADOS score of minimum 6, and their individually matched control participant. As such, the data of 19 pairs of participants were included in our analyses (with 14 HFA participants meeting full ADOS criteria, of which 3 women). While not all participants met ADOS criteria, individuals with HFA often score just below the threshold (Magnée et al., 2008; Zwickel et al., 2011): it is not only likely that many of them have learned to compensate, intervention may also have improved their functioning. Moreover, recent studies have shown that female individuals with HFA have even more difficulties to reach cut-off scores of diagnostic instruments derived

from studying the disorder in males (Dworzynski, Ronald, Bolton, & Happé, 2012; Kopp & Gillberg, 2011). Our initial ASD group contained a roughly equal number of males and females (10 out of 23 individuals), while only 5 females reached 6 as a minimum total ADOS score (out of 19 individuals). Two participants from the HFA group were additionally excluded from analyses, respectively because we retained less than 30% of one individual's data due to a technical error and because of the other showing an overall mean reaction time that was more than 3 standard deviations from the group average. The remaining participant groups (CON: n = 19; HFA: n = 17), were well matched for gender, handedness, age, and full-scale IQ score (see table 1). Due to missing data, the SRS-A questionnaire data of 2 individuals from the CON group, the AQ questionnaire data of 1 participant with HFA. On average, individuals in the HFA group scored well above ADOS and autism cut-offs of the AQ (Baron-Cohen et al., 2001; Lord et al., 2000). As one could expect, t-tests showed highly significant differences between the mean total dimensional scores on the SRS-A and on the AQ questionnaires. Participant characteristics and statistics are summarized in table 1.

Procedure

For both groups, the EEG-experiment was part of a larger battery of tasks (not presented here), which took place in two experimental sessions (with approximately 3 weeks time in between). Both sessions took place in a dimly lit and sound-attenuated room. In the first session, the EEG-data were gathered, with this study being the second of two unrelated EEG-studies. In the second session, each participant completed 2 behavioral tasks (not reported here) and demographic data were gathered (ADOS-interview, IQ-assessment and questionnaires). We derived the participants'

status as ‘high functioning’ from an IQ-score estimation using the KAUFMAN 2 short form Wechsler Adult Intelligence Scale III (full scale IQ ≥ 85; see (Minshew, Turner, & Goldstein, 2005) for the use in ASD), if no recent standardized cognitive assessment was performed (within 5 years prior to participation). A formally trained researcher administered the ADOS-Module 4 with participants belonging to the HFA group (Lord et al., 2000).

Stimuli and task

The established imitation inhibition paradigm was adopted for this study (see figure 1; Brass et al., 2000). We instructed participants to execute finger movements in response to symbolic cues displayed between the index and middle finger of a videotaped hand. More specifically, participants had to respond to the digit ‘1’ by lifting their index finger and to a ‘2’ by lifting their middle finger. At the same time, the hand on the computer screen executed either an index finger movement, a middle finger movement or no movement at all. Each trial started with a frame showing a hand in a resting position (2000ms), mirroring the right hand of the participant. Two consecutive frames (34 ms each) followed that frame, showing the finger movement with the number (for congruent and incongruent trials) or just the number (for baseline trials). Then, a picture showing the end position of the hand and the number was presented (1300 ms). The three movement frames gave the impression of a lifting movement of the index or middle finger, respectively. In between trials, a black screen was presented (2000 ms.).

The experiment was conducted in an electrically shielded, dimly lit and sound attenuated room. All visual stimuli were 300x200 pixels large and were centrally presented at approximately 60 cm distance from the participant on a 17 inch monitor.

The participant's index and middle finger of the right hand were placed on a response-box with four light sensors. Reaction times of the onset of the finger lifting movements were recorded with the two leftmost light sensors of this device. A keyboard was placed within reach of the left hand. Stimulus delivery and data acquisition were achieved by means of the program Presentation (Neurobs), ran on a HP Compaq desktop with Windows XP driver. A 24-trial practice phase preceded the experiment. After this, 50 congruent trials (C), 50 incongruent trials (I) and 50 baseline trials (B) were randomly presented, leading to 150 experimental trials in total. Index finger and middle finger movement pictures were equiprobable per condition. Intermittent breaks occurred after 50 trials, resulting into 2 self-paced pauses.

EEG recording and analyses

The EEG-data were recorded with a Biosemi ActiveTwo system (at a sampling rate of 1024 Hz). We placed 64 active Biosemi EEG-electrodes according to the International 10-10 system using an elastic cap. For offline re-referencing, two electrodes were placed on the mastoids, fixed with two-sided adhesive collars. Bipolar electrodes were placed with left and right canthal montage and additionally above and below the left eye to measure eye movements, all fixed with two-sided adhesive collars. Electrode offsets were kept between -25 and 25 μV at all electrodes. We used BrainVision Analyzer 2 (BVA 2; Brain Products) to analyze the data. We re-referenced the data offline to the average of the left and right mastoid. Following our earlier study (Deschrijver et al., in press), we then applied a high pass filter of 0.1 Hz (time constant 1.5915, slope 48dB/octave), a low pass filter of 30 Hz (slope 24dB/octave), and a notch filter of 50 Hz. Bad channels were estimated from the

signals of all other electrodes using spherical splines. Prior to averaging, we used the Gratton and Coles algorithm (Gratton, Coles, & Donchin, 1983), as implemented in Brainvision Analyzer 2.0, for automatically correction epochs containing eye movements by means of the bipolar electrodes around the eyes. For all other electrodes, an automatic artifact rejection included a gradient check (maximum allowed voltage step: 50 µV/ms within 200 ms before and after the locked event), a minimum/maximum amplitude check (-100 µV and 100 µV respectively), and a low activity check (0.5 µV within an interval length of 100ms). We time-locked the stimulus-related ERP components (N190 and P3) to the onset of the first frame with an instruction number (directly following the resting position frame) and the response-related RP to the moment at which the participant's finger is lifted off the response box, as measured by the light sensors. We collapsed the data over left and right finger movement observations because we were primarily interested in congruency-related processes. Only trials for which the participants produced the correct response between 200 and 1200 ms after stimulus onset were included in the analyses. All epochs received a baseline correction of 100 ms before stimulus onset. On average, the CON group lost 6.19 out of 50 trials per condition due to erroneous responses and/or artefact rejection, while the HFA group lost 4.86 out of 50 trials per condition. Groups did not differ in the number of trials excluded ($t(34) = 0.88$; $p = 0.38$).

All statistical analyses were performed with SPSS Statistics 22. For the N190 and P3, we identified time windows and relevant electrode sites at stable peak topographies (see figure 2) and performed analyses on exported mean area amplitudes. For the N190, we focused on the time window from 190 to 210 ms, and for the left N190, we pooled the activity per condition at left hemispheric electrodes

P5, P7 and PO7; for the right N190, we pooled the activity per condition at the right hemispheric electrodes P6, P8 and PO8. For the stimulus-locked P3, we pooled the activity at electrodes CPz, Pz and POz per condition in the time window from 350 to 400 ms. Based on earlier research (Leuthold & Schröter, 2011; Rigoni et al., 2013; Shibasaki & Hallett, 2006), we identified the RP component in the response-locked segments as the gradient shift preceding the steep negative slope before response onset at electrode FCz (i.e., from -400 to -100 ms for the current dataset). To disentangle the activity of the supplementary motor area, related to motor preparation processes, from contaminating activity related to motor execution processes in the M1, we increased the spatial resolution of the EEG-signal by means of Laplacian transformations (Rigoni et al., 2013; Tandonnet et al., 2005; Vidal et al., 2003). Due to the poor spatial resolution of the EEG-signal, volume conduction effects smear the distribution of the potentials at the scalp level, therefore producing overlapping effects of motor execution and motor preparation processes within the RP (Rigoni et al., 2013). The Laplacian transformation removes the blurring effect of the diffusion of currents through the skull and acts as a high-pass filter. We estimated surface Laplacians from the averaged monopolar EEG signal. First, we interpolated the signal with the spherical spline interpolation procedure, and then computed second derivatives in the two dimensions of the space (degree of spline = 3, maximum degrees the Legendre Polynomial = 15. Conform earlier studies (e.g., Rigoni et al., 2013; Vidal et al., 2003) and the observed topography (figure 2), we conducted the RP-analyses on electrode FCz.

We analyzed results of both behavioral and EEG-data by means of one-way within-subjects ANOVAs with Condition as a within-subjects factor (including the levels: B, C, I) and Group as a between-subjects factor. For the N190 analyses, we

additionally included a factor Hemisphere (with the levels left and right). Greenhouse-Geisser corrections were applied where needed. We used repeated-measures t-tests for paired comparisons. Because of the non-parametric (non-normal) distribution of the data, Spearman correlation coefficients were used for correlational tests.

Results

Behavioral results

An ANOVA on the reaction time data yielded a significant effect of Condition ($F(2, 68) = 79.54$, $p < 0.000$). Reaction times for incongruent trials were larger ($M = 565.11$, $SD = 112.68$ across groups) than for baseline trials ($M = 536,84$ $SD = 101.85$ across groups), whereas the congruent trials elicited the fastest responses ($M = 485.89$, $SD = 85.16$ across groups). Though the interference effect was numerically larger in the HFA group (93ms) than in the CON group (66 ms), the Condition by group effect only trended to significance ($F(2, 68) = 2.63$, $p = 0.08$). To investigate this trending effect further, we decided to test this effect in the initial broader ASD group (also including adults with an ASD diagnosis who scored lower than 6 on the ADOS) and its matched controls. In these groups, the interaction between condition and group was significant ($F(2, 86) = 3.39$, $p < 0.05$), suggesting that the previous analyses might have lacked sufficient power. Paired comparisons of this effect showed that the reaction time difference between congruent and baseline trials was larger in the initial ASD group than in its matched CON group ($t(43) = 2.05$, $p < 0.05$), while there was no group difference between the incongruent and baseline difference ($t(43) = 0.34$, $p = 0.74$). As such, the initial broader ASD group did show a larger behavioral motor interference effect: the group reacted faster than its matched

control individuals in congruent trials where a compatible movement was observed, as compared to baseline trials where no movement was observed. For all other analyses, we returned to the restricted HFA group that was selected on the basis of an ADOS score of mimimum 6 (see participant characteristics).

Analyses on the error percentages in the HFA group and their matched controls (including erroneous as well as missed responses) showed a significant difference between the 3 conditions ($F(2,68) = 15.66$, $p < .000$) that did not show any modulations by Group ($F(2, 68) = 0.02$, $p = 0.98$). More specifically, across groups, we found that the incongruent trials elicited more errors (M = 0.03%, SD = 0,03%) than the congruent (M = 0.01%, SD = 0,02%) or baseline trials (M = 0.01%, SD = 0,02%). No other effects reached significance.

EEG-results

P3

In the P3 component, the HFA group and their matched controls showed significant differences between the three conditions overall ($F(1.5,51.4) = 9.95$, $p = .001$), which did not interact with the factor Group ($F(1.5,51.4) = 0.17$, $p = 0.78$; see figure 4 and 5). The congruent trials and the incongruent trials elicited larger P3 amplitudes than baseline trials ($t(35) = 3.83$, $p = .001$ and $t(35) = 3.60$, $p = .001$ respectively), replicating our findings in neurotypical adults (Deschrijver et al., in press). Incongruent trials elicited a numerically smaller P3 amplitude than congruent trials across groups, a difference which trended to significance ($t(35) = 1.93$, $p = .06$). No other effects reached significance.

RP

An ANOVA on the RP Laplacians showed a significant difference between the three conditions ($F(2, 68) = 6.91$, $p < .005$). Importantly, the interaction of Condition and Group was also significant ($F(2, 68) = 5.60$, $p < .01$, see figure 4 and 5). Surprisingly, the difference between the congruent and the incongruent condition was not significantly altered in the HFA group ($t(35) = 0.57$, $p = .46$). Instead, paired comparisons showed that the difference between the congruent condition and the baseline reversed in the HFA group as compared to the CON group ($t(35) = 9.09$, $p = 0.05$): While RP Laplacians for the congruent condition were numerically smaller than those for the baseline condition in the CON group, congruent trials elicited numerically larger RP Laplacians than the baseline condition in the HFA group. Additionally, paired comparisons showed that the difference between the baseline and the incongruent condition was larger in the HFA group than in the CON group ($t(35) = 8.33$, $p < 0.01$): incongruent trials were associated with a larger RP in individuals with ASD than in CON individuals, as compared to baseline trials. No other effects reached significance.

N190

We identified clear N190 topographies in both the HFA and the CON group (see figure 2). The ANOVA yielded a significant main effect of Condition ($F(1.63,70) = 16.27$, $p < 0.001$) and of Hemisphere ($F(1,43) = 10.85$, $p < 0.005$), but no main effect of Group ($F(1,43) =24.37$, $p = 0.15$). No interaction between Condition and Group was present ($F(1.6,69.93) = 0.73$, $p = 0.46$). When collapsed over groups and hemispheres, the baseline condition elicited smaller N190-amplitudes than the

congruent and the incongruent condition ($t(44)= 2.84$, $p < 0.01$; and $t(44)= 2.94$, $p = 0.005$ respectively). No difference existed between the congruent and incongruent conditions when collapsed over groups and hemispheres ($t(44)= 1.03$, $p = 0.31$). In other words, overall, we did not observe a congruency difference within the N190 component. No other effects reached significance (see figure 5).

Correlational results

Given the results of the Laplacian RP potential in the HFA group, we computed an index for the difference between incongruent and baseline condition (I-B) and for the difference between congruent and baseline condition (C-B), as well as an index for the congruency difference (I-C). We also computed an index for the behavioral interference effect within the reaction times (C-I). We tested for correlations between these measures and ASD symptoms as assessed with the ADOS total score and self-report measures of (social) autistic traits (AQ total score and SRS-A). None of these correlations were found significant.

Discussion

The current study examined aberrant neural processes underlying motor interference in adults with ASD. To our knowledge, this is the first study that tested the imitation inhibition task in ASD via a neuroimaging technique. We used EEG to disentangle low-level perceptual and motor from high-level social processes. On the behavioral level, the HFA group showed a numerically increased motor interference effect in reaction times, though this effect only reached significance in the initial broader ASD group (including adults with an ASD diagnosis who scored lower than 6

on the ADOS). On the neurophysiological level we found a similar congruency-related P3 in the HFA and control group, indicating no deficit in self-other distinction in the imitation-inhibition task in HFA. Interestingly, however, we found that the HFA group differed from the control group in the amplitude of the RP.

The motor interference effect: behavioral results

The HFA group showed a numerically larger motor interference effect than the CON group, a group difference that trended to significance. In the inital broader group with an ASD diagnosis group (including adults with an ASD diagnosis who scored lower than 6 on the ADOS), we did observe a significantly larger congruency difference, indicating that the previous analyses might have lacked power. In this initial broader ASD group, the observation of a compatible hand action lead to relatively faster responses, reflected in a larger reaction time difference between congruent and baseline trials for this group as compared to their matched controls. The findings are in line with some earlier empirical studies that showed increased motor interference effects in ASD (e.g. Bird et al., 2007; Sowden, Koehne, Catmur, Dziobek, & Bird, 2015; Spengler et al., 2010) and with clinical observations of hyperimitation such as echolalia and echopraxia (Lord et al., 2000; Spengler et al., 2010). Other studies on automatic imitation in ASD, however have reported typical or near-typical motor interference effects in autistic groups (Gowen et al., 2008; Grecucci et al., 2013; Press et al., 2010; Sowden et al., 2015). As noted by Sowden and colleagues (2015), this may be due to the use of small sample sizes, or incorporation of emotional/face materials (Gowen et al., 2008; Grecucci et al., 2013; Press et al., 2010; Sowden et al., 2015), which might have affected neural processes more strongly than automatic action imitation mechanisms. To reach a final

conclusion about the hyperimitation effect in ASD, a meta-analytic approach seems advisable.

High-level social cognitive processes: P3 results

In contrast to our main hypothesis, we did not detect differences between the HFA and the CON group in the P3 ERP-component. Observed hand movements that were compatible to own motor intentions yielded numerically larger P3-components than observed hand movements that were incompatible to own motor intentions over both groups. This suggests that, at high levels of processing, individuals with HFA may be able to differentiate observed hand actions that are incompatible to planned hand actions from observed hand actions that are compatible to planned hand actions. Indeed, the HFA group showed a congruency difference within the P3 component that was at least equally strong and numerically even larger than that in the CON group. Because of this unexpected result, we cannot conclude from our data that (all) individuals with ASD show diminished abilities to distinguish between self and others based on actions at higher levels of processing (Hamilton, 2013; Southgate & Hamilton, 2008; Spengler et al., 2010).

While EEG and fMRI shouldn't be expected to yield overlapping results, they can be seen as complimentary: We had hypothesized that the P3 may be able to capture high-level self-other distinction deficits in adults with HFA, since the TPJ and aMFC have been noted among others as neural sources of the P3-component (Blanke et al., 2005; Bledowski et al., 2004; Longo et al., 2012; Mulert et al., 2004; Verleger, 2008). The involvement of the TPJ and aMFC in the imitation inhibition task has been demonstrated in neurotypical individuals (Brass et al., 2005) yet there is no study to our knowledge that shows reduced activity in these areas during the task in

individuals with ASD: It has only been shown that the motor interference effect is functionally related to activity in the TPJ and MPC areas during *mentalizing* (Brass et al., 2009; Spengler et al., 2010). As such, it might be the case that individuals with ASD (or individuals with HFA in specific) will not show reduced brain activity at high-level social cognitive brain areas within the imitation inhibition task. Future research in this area, potentially combining EEG and fMRI techniques, is warranted.

The effect of perception on action: RP results

The response-locked Readiness Potential (RP) Laplacian is known to magnify with increasing complexities of motor preparation (Leuthold & Schröter, 2011; Rigoni et al., 2013). As was observed in our previous study (Deschrijver et al., in press), neurotypical adults in the current study showed (numerically) smaller RP Laplacians for congruent trials as compared to incongruent trials (or baseline trials), suggesting facilitated motor preparation for own hand actions after observing a compatible hand action. RP Laplacians in the HFA group were significantly different from those in the CON group. In the HFA group, the RP Laplacian for *congruent* trials was (numerically) larger than for the baseline trials, suggesting that motor preparation might have been more 'complex' for these individuals when observing compatible finger movements as compared to when no hand action was observed. So in contrast to individuals without ASD (see also Deschrijver et al., 2016), the group with HFA did not experience any facilitating effect by a human hand observation that 'mirrored' their own hand movement. Moreover, *incongruent* trials elicited larger RP Laplacians than the baseline trials in the HFA group. This suggests that trials showing incompatible hand movements interfered with action preparation of own actions for individuals with HFA. In the control group, we did not observe such an interference

effect for incongruent trials within the RP Laplacians (nor in the current study nor in the healthy adults of our earlier study; Deschrijver et al., 2016). In sum, it seems that in the HFA group, *any* observed human hand movement was experienced as more strongly interfering with one's own action preparation, when compared to trials where no hand action was observed. Surprisingly however, the difference between the congruent and the incongruent conditions was not significantly different between the two groups. As such, it is not likely that motor preparation differences will account for increased motor interference effects observed in individuals with ASD in this or other studies (Bird et al., 2007; Sowden et al., 2015; Spengler et al., 2010).

ASD has long been associated with movement abnormalities (Rinehart, Bradshaw, Brereton, & Tonge, 2001), and studies have ascribed this to atypical movement preparation (Dowd, McGinley, Taffe, & Rinehart, 2012; Nazarali, Glazebrook, & Elliott, 2009; Rinehart et al., 2006, 2001). Atypical motor preparation abilities in ASD have primarily been related to disturbances in the supplementary motor area circuity (Rinehart et al., 2001), the neural area which is thought to underlie the RP Laplacian (Rigoni et al., 2013; Vidal et al., 2003). It should be noted that the original imitation inhibition paradigm we used (Brass et al., 2000; Brass, Zysset, & von Cramon, 2001) does not include a non-social control condition. This would have allowed us to exclude the possibility that the observed group difference is due to a non-social effect, that is, the mere observation of (non-biological) movement as compared to when no movement is observed (baseline condition). However, a previous study showed that individuals with ASD show no difference as compared to control individuals in the brain activity in response to non-social arrows in the flanker task (Dichter & Belger, 2007). Moreover, interference tasks that included non-social control conditions did not observe differences for ASD individuals within these

conditions (Gowen et al., 2008), which suggest that they generally have no heightened sensitivity for non-social conditions. As such, we consider non-social effects not likely to account for the current results.

The effect of action on perception: N190 results

Previous fMRI studies of the imitation inhibition task (Brass et al., 2005; Spengler et al., 2010) have not reported an influence of action intention on visual processes, which makes it likely that such processes are rather subtle (see also Deschrijver et al., in press). In the current study, we could not replicate our earlier finding that action intentions affect early visual processes (Deschrijver et al., in press), as reflected in the absence of a congruency effect within the N190-amplitudes. Given this failure to replicate this finding, it is difficult to draw any conclusion about a potential impairment of effects of action on perception in ASD. Further research with larger sample sizes is warranted to explore the role of this potental neural source of imitative control mechanisms in populations with and without ASD.

Conclusion

In sum, the current results suggest that neural differences within automatic imitation paradigms in ASD populations might be situated on the level of motor preparation, rather than (only) at high-level social cognitive levels (Spengler et al., 2010). Overall, the findings contrast with theoretical views where individuals with ASD are thought to have an impaired mirror neuron system per se (Iacoboni & Dapretto, 2006; Oberman et al., 2008; Williams et al., 2004). In the future, if replicated, the findings may lead to the development of interventions centred around

movement preparation difficulties in ASD, though follow-up research is certainly needed here (for a review on the efficacy of currently existing motor interventions in ASD, see Baranek, 2002). The results may have important implications for research to control over imitation as well, because they highlight the importance of intact motor preparation processes that are at play in the imitation inhibition task.

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Figure Captions

Figure 1. Design of the paradigm

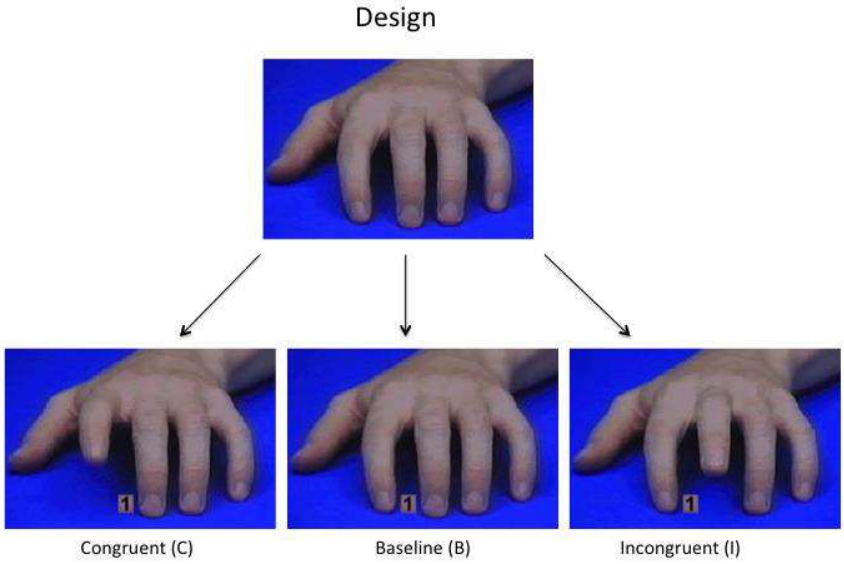


Figure 2. Topographies of the visual N190, the P3 and the RP Laplacian in their respective time frames of interest. Top: CON-group. Bottom: HFA group. Viewpoint from above, front of the head at the top. Left (L) and right (R) side of the head indicated. Electrodes of interest are marked in black.

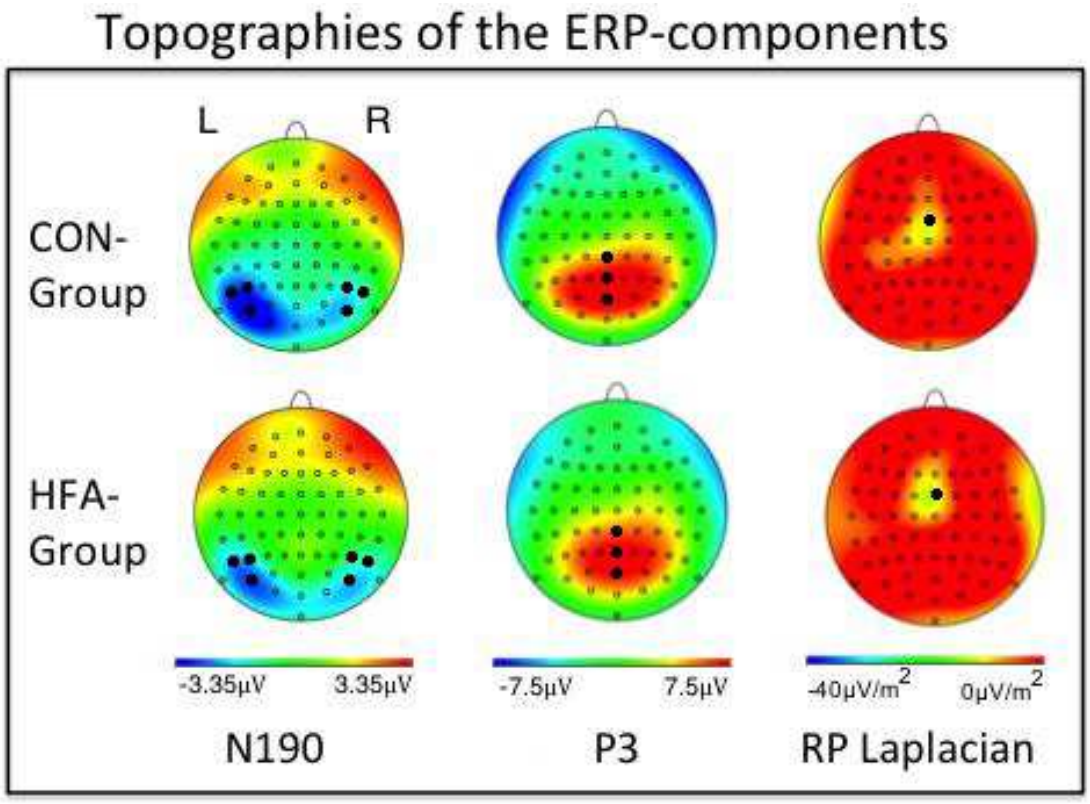


Figure 3. Results and correlation charts. Data of the groups restricted on the basis of the ADOS (see Participant). (Error bars denote standard error. **: test is significant at the 0.01 level, *: test is significant at the 0.05 level, + test is significant at the 0.10 level (2-tailed).) Legend: 'C' for congruent; 'B' for baseline; 'I' for incongruent. A. Reaction times chart. B. P3 amplitude chart. C. RP Laplacian chart.

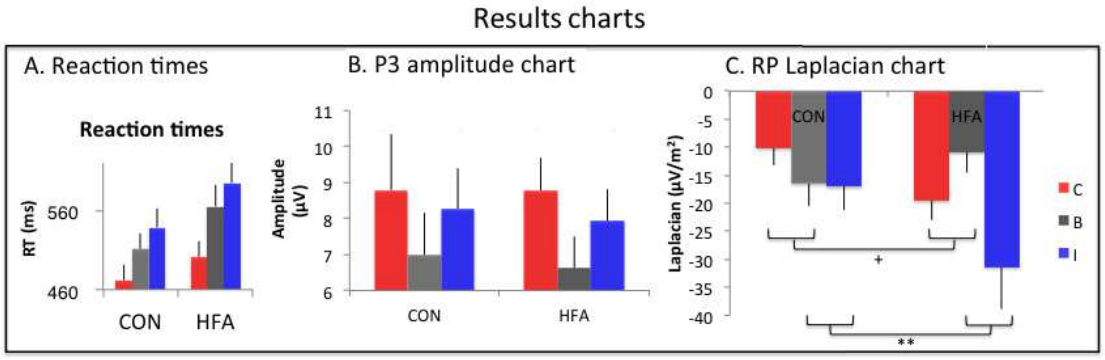


Figure 4. P3 and RP components. Pooled ERPs over the relevant electrodes for the P3.

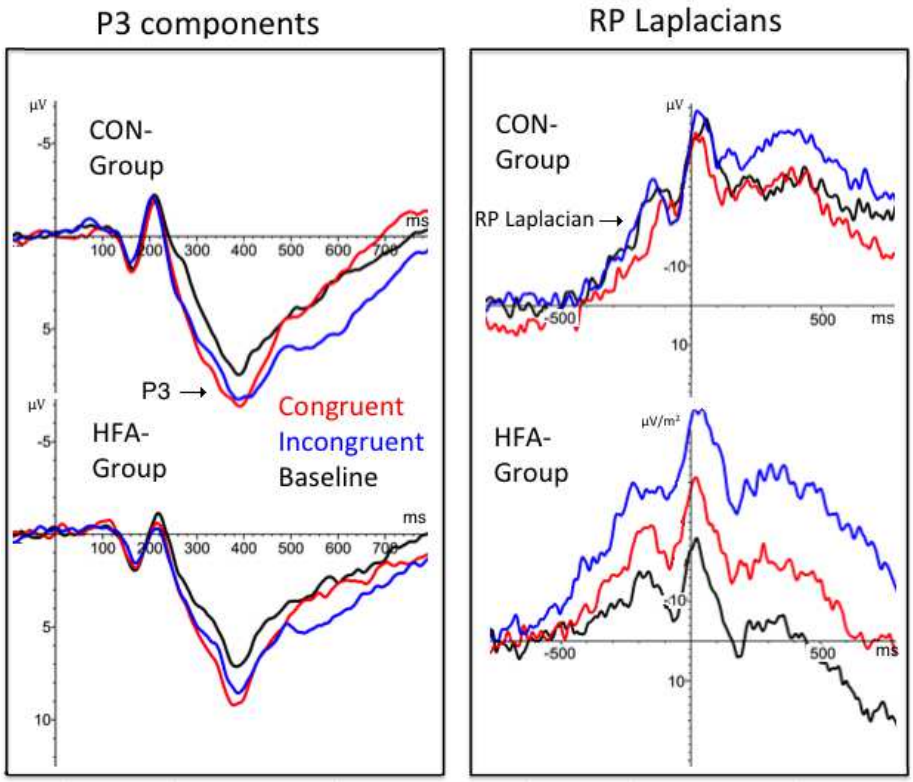
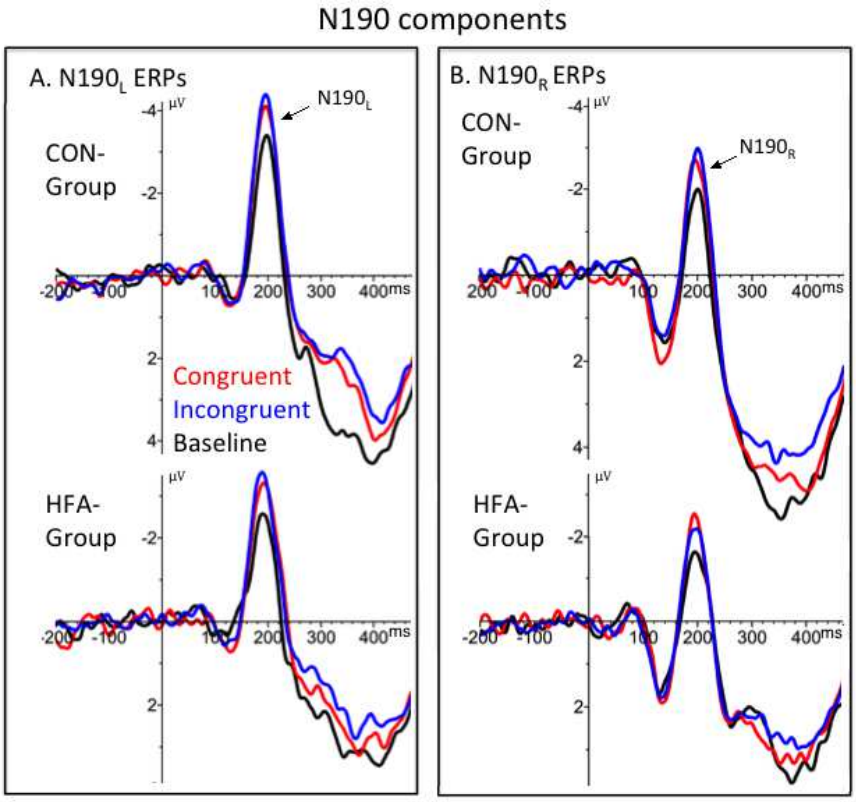


Figure 5. N190 components. Pooled ERPs over the relevant electrodes.



Tables

Table 1: Participant details (***: test is significant at the 0.001 level (2-tailed)).

	HFA	CON	t	p-value
Number of male participants	11	12	N.A.	N.A.
Number of right-handed participants	15	18	N.A.	N.A.
Mean age (S.D.)	33.06 (6.54)	31.79 (6.54)	0.58	0.57
Mean full-scale IQ (S.D.)	111.88 (15.10)	117.74 (13.84)	1.21	0.23
Mean ADOS communication (S.D.)	2.59 (1.12)	N.A.	N.A.	N.A.
Mean ADOS social interaction (S.D.)	6.41 (2.15)	N.A.	N.A.	N.A.
Total score Autism Questionnaire (S.D.)	33.19 (8.29)	11.16 (4.21)	9.69	0.00***
Total score Social Responsiveness Scale (S.D.)	162.63 (35.59)	93.82 (14.05)	7.22	0.00***

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