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ORIGINAL PAPER

Atypical Response to Caregiver Touch in Infants at High Risk for Autism Spectrum Disorder

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Abstract
Atypical response to tactile input is associated with greater socio-communicative impairments in individuals with autism spectrum disorder (ASD). The current study examined overt orienting to caregiver-initiated touch in 12-month-olds at high risk for ASD (HRA) with (HRA+) and without (HRA−) a later diagnosis of ASD compared to low-risk comparison infants. Findings indicate that infants that go on to receive a diagnosis of ASD may more frequently fail to shift their attention in response to caregiver touch and when they do, they may be more likely to orient away from touch. Additionally, failure to respond to touch predicts ADOS severity scores at outcome suggesting that atypical response to touch may be an early indicator of autism severity.

Keywords Infant siblings · Autism · Touch · Attentional disengagement · Social orienting

Deficits in social communication are among the defining features of autism spectrum disorder (ASD; APA 2013). Although there is a vast amount of research exploring social impairments in ASD, mechanisms underlying these deficits are not well understood (Volkmar 2011). Many have argued that atypical development of socio-communicative skills may result from differences in how those with ASD attend to their environment during the first few years of life (Dawson et al. 2004), due to a domain-general impairment in basic attentional processes (i.e., disengaging attention; Keehn et al. 2013) or a domain-specific deficit in social motivation and orienting (Dawson et al. 2004).

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Since adaptive allocation of attention to surrounding input is crucial to the development of social communication (Ibanez et al. 2008), early attentional dysfunction could impact the emergence of later-developing social communication. Children with ASD exhibit early and pervasive difficulties in attention modulation (Keehn et al. 2013) and show restricted and selective attentional patterns at the expense of attending to the crucial aspects of the social environment (Lovaas et al. 1979). For example, Dawson et al. (1998, 2004) have demonstrated that deficits in orienting to auditory social information is related to poor joint attention and is associated with concurrent and later language abilities in children with ASD. Similar evidence of impaired attentional shifting to people and objects has been reported in the visual domain based on retrospective video analysis of 9- to 12-month-olds (Baranek 1999), prospective longitudinal studies of infants at high risk for ASD (Sacrey et al. 2013), and analysis of 20-month-olds with ASD (Swettenham et al. 1998). Together, these studies suggest that atypical attentional orienting to both auditory and visual information is present during early development in children with ASD.

Touch, another key channel through which we receive social information (Gallace and Spence 2010), is one of the first senses to develop (Gottlieb 1971; Maurer and Maurer 1988), and plays a vital role in human interactions (Dunbar 2010; Hertenstein et al. 2006) including, bonding (Field 2001), secure attachment (Weiss et al. 2000) and reducing distress (Hertenstein 2002). Importantly, the reward value associated with social touch can influence neural and social development throughout an individual's lifespan (Cascio et al. 2018). Furthermore, because maternal touch occurs frequently and affects the quality of mother–child dyadic interactions, for example, by increasing positive affect in infants (Stack and Muir 1992), it may facilitate the development of early social communication skills. Recent findings suggest that touch may support infants' speech perception (Seidl et al. 2015) and that early language input is often coupled with caregiver touch (Abu-Zhaya et al. 2017; Nomikou and Rohlfing 2011). Thus, touch is prevalent and may play a role in social and communicative development.

Prior studies show that the majority of individuals with ASD are hypo- or hyper-sensitive to touch (Baranek et al. 2006). These atypical patterns of tactile sensitivity are well documented from first-person accounts of individuals with ASD (Cesaroni and Garber 1991; Minshew and Hobson 2008), parental reports (Baranek et al. 2006; Leekam et al. 2007), clinical observation (Baranek and Berkson 1994; Baranek 1999), and neuroimaging studies (Kaiser et al. 2015). Furthermore, aberrant responses to touch have been associated with socio-communicative impairments in ASD (Foss-Feig et al. 2012; Hilton et al. 2010). These findings suggest that the processing of tactile stimuli may be altered in individuals with ASD and that this impairment may affect their social and communicative development.

Given the evidence that social orienting to visual and auditory information is impaired in ASD, and, separately, that touch is a key element in early dyadic interaction, the present study sought to investigate overt attentional orienting to naturally-occurring caregiver-initiated touch in high-risk infants. We examined orienting frequency in response to caregiver-initiated touch in 12-month-olds at high risk for ASD (HRA) that did (HRA+) or did not (HRA−) meet later diagnostic criteria for ASD compared to low-risk comparison infants (LRC−; infants none of whom were later diagnosed with ASD). Infants in the three groups were matched on the amount of touches they received, as it allowed us to control for the opportunities each infant received to respond to touch. We reasoned that, touch responsivity might be related to outcome status since it has been established that young infants with ASD often show hypo-responsiveness to sensory input (Baranek et al. 2013) and also exhibit impaired social orienting (Baranek 1999; Dawson et al. 2004; Swettenham et al. 1998). Second, given the evidence suggesting hyper-responsivity (Baranek et al. 2006) and tactile defensiveness in ASD (Baranek et al. 1997) we predicted that, in instances where an infant is already attending to the touch-related stimuli (e.g., the infant is looking at her caregiver's face), an infant who will go onto an ASD diagnosis may more frequently orient attention away from touch compared to the other two groups. Lastly, because prior research has demonstrated that touch may facilitate early language and social communicative development (Abu-Zhaya et al. 2017; Nomikou and Rohlfing 2011; Seidl et al. 2015), we examined whether early responsivity to touch was associated with later language and ASD symptomatology. Since atypical responsiveness to tactile stimuli in ASD has been linked with greater impairments in social communication, nonverbal communication, and repetitive behaviors (Foss-Feig et al. 2012), we predicted that atypical attentional orienting to caregiver touch at 12 months would be associated with poorer language abilities and greater socio-communicative impairment at 24 or 36 months.

Methods

Participants

Data for 39 (13 HRA+, 13 HRA−, 13 LRC−) 12-month-olds and their caregivers were selected from a larger sample (N = 144) of infant–caregiver dyads that was obtained as a part of a prospective, longitudinal study. All infants had a minimum gestational age of 36 weeks, with no history of prenatal or postnatal medical or neurological problems, and no known genetic disorders (e.g., fragile-X, tuberous sclerosis). LRC infants had a typically developing older sibling and no family history of ASD or other neurodevelopmental disorders. Infants at high risk for ASD had an older sibling with a diagnosis of autistic disorder, Aspergers disorder, or pervasive developmental disorder—not otherwise specified (based on DSM-IV criteria). Diagnostic information for the proband was confirmed using the Autism Diagnostic Observation Schedule (ADOS; Lord et al. 2000), the Social Communication Questionnaire (SCQ; Rutter et al. 2003), and/or the Pervasive Developmental Disorders Screening Test-II (PDDST-II; Siegel 2004) if the older sibling was under 4 years of age. All infants were followed longitudinally to determine ASD outcome. After their last visit at either 24 or 36 months, HRA infants were further subdivided into positive (HRA+) and negative (HRA−) ASD outcome groups. Outcome data were collected at 24 or 36 months because not all participants attended both 24 and 36-month visits. For example, out of 13 participants in each of the three groups, only 10 HRA+, 9 HRA−, and 10 LRC− participants attended 36-month visits, whereas only 12 HRA+, 12 HRA−, and 11 LRC− attended 24-month visits. For this study, we included 36-month ADOS severity scores for all those who attended their 36-month visit. Next, we examined whether those who missed their 36-month visit attended their 24-month visit. If they did, their 24-month ADOS severity score was used. All infants in the HRA+ group received a final clinical judgment of ASD by a licensed clinical psychologist (blind to group membership) with expertise in the area of ASD and neurodevelopmental disorders after review of all information, including videos and scores from the ADOS (Gotham et al. 2007) from all available lab visits.

In order to control for inter-individual variability in the amount of touch provided by caregivers, first we identified HRA+ participants who completed their 24- and/or 36-month visits from our larger sample. This yielded a sample of 18 HRA+ participants. Two participants in the HRA+ group were excluded because they received fewer than five touch bouts. Remaining infants in the HRA+ (n = 16) group were individually matched based on the frequency of touch bouts provided to them by their caregivers (± 3 touch bouts) with infants in both the HRA− and LRC− groups. A matching window of ± 3 touch bouts was chosen as it provided flexibility to find a match across the three groups, while reducing the variability in the frequency of touches (and thus orienting opportunities) in a given trio. For matching with all HRA+ participants, a group of 21 HRA− and 33 LRC− participants were randomly selected from our larger sample (N = 144). A small group of LRC infants (n = 3) with a later diagnosis of ASD were excluded prior to randomly selecting touch-matched comparison infants due to the low number of infants in this group. Upon matching, 3 HRA+ participants were excluded because there were no matches within the HRA− and LRC− groups. This yielded a final sample of 13 trios matched on touch frequency (13 HRA+, 13 HRA− and 13 LRC−). All the remaining HRA− (n = 8) and LRC− (n = 20) participants who did not find matches with our HRA+ participants were excluded from further analysis. The individualized matching procedure resulted in having 50% HRA+ and 50% HRA− participants at outcome in the HRA group. These three groups did not differ on sex, age, parental education, family income or the frequency of touch bouts (Table 1). There were, however, significant differences in infants' Early Learning Composite Scores (ELCS) on the Mullen Scales of Early Learning (MSEL) at 12 months (Table 1). Specifically, the HRA− group had higher ELCS scores compared to the HRA+, $t(24) = 2.79$, $p = .01$, and the LRC− groups, $t(24) = 2.02$, $p = 0.055$. However, there were no significant differences between HRA+ and LRC− groups, $t(24) = -.54$, $p = 0.60$.

Procedure

At their 12-month visit, caregiver-infant dyads participated in a 10-min free-play session. All dyads were provided with an identical set of age-appropriate toys (e.g., book, ball, toy vehicles) and were instructed to play as they would in any other natural setting. Only sessions with the mother were included in the final sample. The decision to exclude father–infant interactions was based on previous research suggesting that mothers and fathers may interact differently with their children (Walker and Armstrong 1995) and because the vast majority of sessions involved the mother. All free-play interaction sessions were video recorded for later analysis.

Standardized Measures

Mullen Scales of Early Learning

The MSEL is a standardized developmental test for infants and children up to 68 months, and consists of five subscales: gross motor, fine motor, visual reception, expressive language, and receptive language (Mullen 1995). The Expressive Language scale assesses children's verbal responses to questions, and concept formation. The Receptive Language scale assesses children's ability to decode verbal input. Developmental quotients (DQs) were calculated by dividing the subscale age-equivalent score by the child's chronological age and multiplying by 100 (Messinger et al. 2013; Munson et al. 2008). Scores from the verbal domain (mean of Receptive and Expressive Language DQs) were used as our index of language abilities.

Table 1 Participant demographics at 12 months

	HRA+	HRA−	LRC−	Statistic	*p* Value
N (male)	13 (10)	13 (6)	13 (7)	X^2 (2) = 2.87	0.23
Age (days)	377 (13.12), 366–413	376 (11.07), 359–392	374 (10.41), 360-396	$F(2,36) = 0.16$,	0.85
MSEL ELCS	96.31 (14.41), 72–118	112 (14.31), 89–138	99.61 (16.83), 77–134	$F(2,36) = 3.84$,	0.03
Frequency of touch bouts	19.85 (5.08), 14–29	20.31 (6.32), 11–30	20.0 (5.26), 14–29	$F(2,36) = 0.02$,	0.97
Mothers with 4-year college degree or higher %	82	75	80	X^2 (2) = 0.17	0.91
Fathers with 4-year college degree or higher %	73	58	70	X^2 (2) = 0.60	0.74
Family income (% with greater than 65,000)	100	92	78	X^2 (2) = 3.49	0.17
ADOS severity scores at outcome	5.38 (2.50), 2–10	1.30 (0.48), 1–2	1.45 (0.82), 1–3	$F(2, 37) = 27.28$	0.00

Mean (SD), range

Autism Diagnostic Observation Schedule-2

The ADOS-2 is a semi-structured play-based interaction designed to measure autism symptoms in social relatedness, communication, play, and repetitive behaviors. Severity scores from the ADOS-2 diagnostic algorithm were used as symptom measures, with higher ADOS-2 scores reflecting greater severity (Gotham et al. 2007).

Observational Measures

Caregiver Touch and Infant Responses to Touch

Video coding of maternal touches and infant responses to touch was performed using ELAN software (Brugman and Russel 2004). Teams of two trained coders, blind to group membership, evaluated the frequency, type, and location of mother-initiated intentional touches that were delivered to infants during free-play interactions (e.g., a tap on the infant's leg with right hand with a toy). Intentional touch was defined as any touch that was deliberately initiated by the mother. Accidental touches (e.g., mother accidentally brushing the infant's shoulder while trying to reach for a ball) were extremely infrequent and were not coded. Infants' looking behaviors before, during, and after every touch bout were then coded. Each touch event and the associated infant response was agreed upon by both the coders before annotating.

For each hand, touch location (e.g., on the leg) and touch type (e.g., tickle) were coded. Touch events were then combined into touch bouts defined as simultaneous touch events delivered by both hands or consecutive touch events presented by either one or both hands that occurred within 1 s of each other (Fig. 1a). For analysis of the different touch types, touches were divided into seven categories based solely on their observable differences (See Supplementary Materials for touch locations and types). For instance, holding, moving, and grabbing were grouped together since they

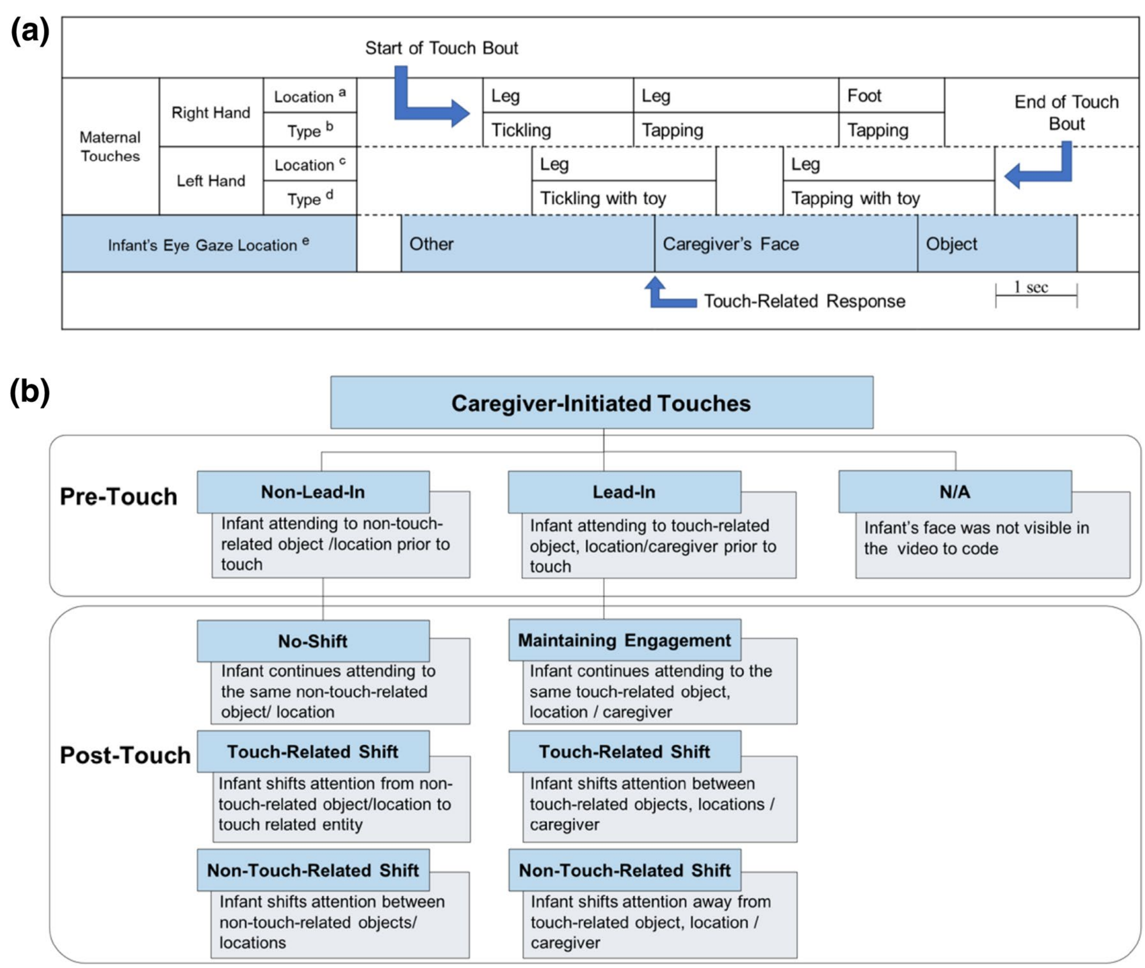

Fig. 1 **a** Illustration of the coding scheme used for the current study. Tiers a, b, c and d show caregiver touches and types delivered by right and left hands respectively. Tier e shows infants' attentional shifts before, during and 1 s after each touch bout. **b** Coding scheme for infant attention in interactions

all involve controlling the infant's body by the caregiver; whereas, brushing, poking, squeezing, and tapping were grouped together as they all include more than one *beat* of the same action. Coding of maternal touches was based on the touch coding scheme used by Abu-Zhaya et al. (2017).

Infants' gaze location prior to the touch was coded by looking at infants' eye gaze and/or head movements (Fig. 1a). For all touch bouts, infant responses were grouped into three pre-touch categories: (1) *Non-Lead-Ins,* (2) *Lead-Ins*, and (3) *N/As* (Fig. 1b). For each touch bout, first, the touch location and/or object of focus were identified by watching the entire interaction in order to confirm whether the infant was looking at any touch-related object or location prior to that touch. For example, if the infant was looking at a puppet prior to a touch and was then touched with this object this would be classified as a *Lead-In* response.

Similarly, post-touch infant responses were coded by looking at infants' overt attentional shifts that occurred during a touch until one second after the end of a touch bout (Fig. 1a). Infant responses that began one second after the end of a caregiver touch bout were not coded. Infants' responsivity to touch was examined by looking at their first overt response after receiving a touch. Infant responses included looking to: (1) the caregiver's face, (2) the caregiver's hand used to deliver the touch, (3) the object used to deliver the touch or in focus during the period of that touch event, and (4) the location of the touch (e.g., infant's leg). Infant responses that could not be identified as any of the above behaviors, were coded as other (e.g., infant looking at her hand while receiving a touch on her foot.). Cases in which infants' responses were not identifiable were coded as N/A.

Next, the two pre-touch categories (Non-Lead-Ins, Lead-Ins) were further divided into three trial types (Fig. 1b). Specifically, the Non-Lead-In category was divided into *No-Shift*, *Touch-Related*, and *Non-Touch-Related* responses. For example, if following a touch, the infant shifts her attention to the caregiver, a touch-related object, or the touch location this was classified as Touch-Related. If the infant shifts her attention to an object not involved in the touch, then this was classified as a Non-Touch-Related response. Similarly, the Lead-In category was divided into three response types: *Maintaining Engagement*, *Touch-Related*, and *Non-Touch-Related* responses. Lastly, percentages of Touch-Related, Non-Touch-Related, and No-Shifts/Maintaining Engagement responses were calculated separately for Lead-In and Non-Lead-In categories by dividing the number of trials in each response type by all responses recorded for that category (i.e., Lead-In, Non-Lead-In). Dividing infant responses into No-Shifts/Maintaining Engagement, Touch-Related and Non-Touch-Related responses allowed us to answer two questions: (1) do infants overtly shift attention in response to touch? (2) Is a shift directed towards or away from a touch? The primary rationale for separating the two pre-touch categories (Non-Lead-Ins, Lead-Ins) was to control for the qualitative difference between two similar infant responses post-touch. For example, in the Non-Lead-in category a No-Shift would imply that the infant was not responsive to the mother's touch, and hence, failed to orient to any touch-related individual, objects, or locations. On the other hand, a Maintaining Engagement response in the Lead-In category which also involves not shifting one's attention post-touch indicates that the infant is continuing to attend to the touch-related entity. The N/A category was excluded from analyses. A second pair of coders, blind to group membership, recoded 20% of the data (n = 8) to check for inter-rater reliability. Pearson's correlations were calculated on the percentage of pre-touch categories (i.e., identification of Non-Lead-In and Lead-In categories based on infant's looking behaviors pre-touch). Similarly, correlation coefficients were calculated between the two coding pairs on the percentages of identifying infants' post-touch responses. Reliability between coders was high ($r = .94$ and $r = .81$, in pre-touch and post-touch infant looking behaviors respectively).

Results

A series of one-way Analyses of Variance (ANOVAs) for each pre-touch category were conducted to explore whether the percentages of Lead-In, Non-Lead-In, and N/A categories differed in the three groups (HRA+, HRA−, LRC−). There were no significant group differences in percentages of Lead-In, $F(2,36) = 0.63$, $p = 0.53$, $\eta_p^2 = 0.03$, Non-Lead-In, $F(2, 36) = 0.79$, $p = 0.46$, $\eta_p^2 = 0.04$, and N/A categories $F(2,36) = 2.76$, $p = 0.08$, $\eta_p^2 = 0.17$. Additionally, the frequency of different touch types received by infants did not vary significantly across the three groups (Supplementary Table 1).

Non-lead-In category

Three independent one-way ANOVAs with percentages of each Response Type (No-Shift, Touch-Related Shift and Non-Touch-Related Shift) x Group (HRA+, HRA−, LRC−) were calculated. Results indicated a significant difference in the percentage of No-Shift responses across the three groups, $F(2,36) = 4.57$, $p = 0.02$, $\eta_p^2 = 0.20$. Follow-up independent samples t-tests showed that the HRA+ infants had a significantly greater percentage of No-Shift responses to caregiver touches in the Non-Lead-In category (41%) compared to LRC− (24%, $t(24) = 2.84$, $p = 0.009$, $d = 1.12$) and HRA− infants (30%, $t(24) = 2.15$, $p = 0.04$, $d = 0.85$). This suggests that infants in the HRA+ group were less responsive to caregiver touch compared to HRA− and LRC− infants when they were engaged in some other non-touch-related activity prior to caregiver-initiated touch. However, there were no significant differences in the percentage of Touch-Related, $F(2,36)=1.05$, $p=0.35$, $\eta_p^2=0.05$, and Non-Touch-Related Shifts, $F(2,36)=0.70$, $p=0.50$, $\eta_p^2=0.03$ between the three groups (Fig. 2a; Supplementary Table 2).

Lead-In Category

Three independent one-way ANOVAs with percentages of each Response Type (Maintaining Engagement, Touch-Related Shift and Non-Touch-Related Shift) x Group (HRA+, HRA−, LRC−) were conducted. Results revealed no significant group differences in the percentage

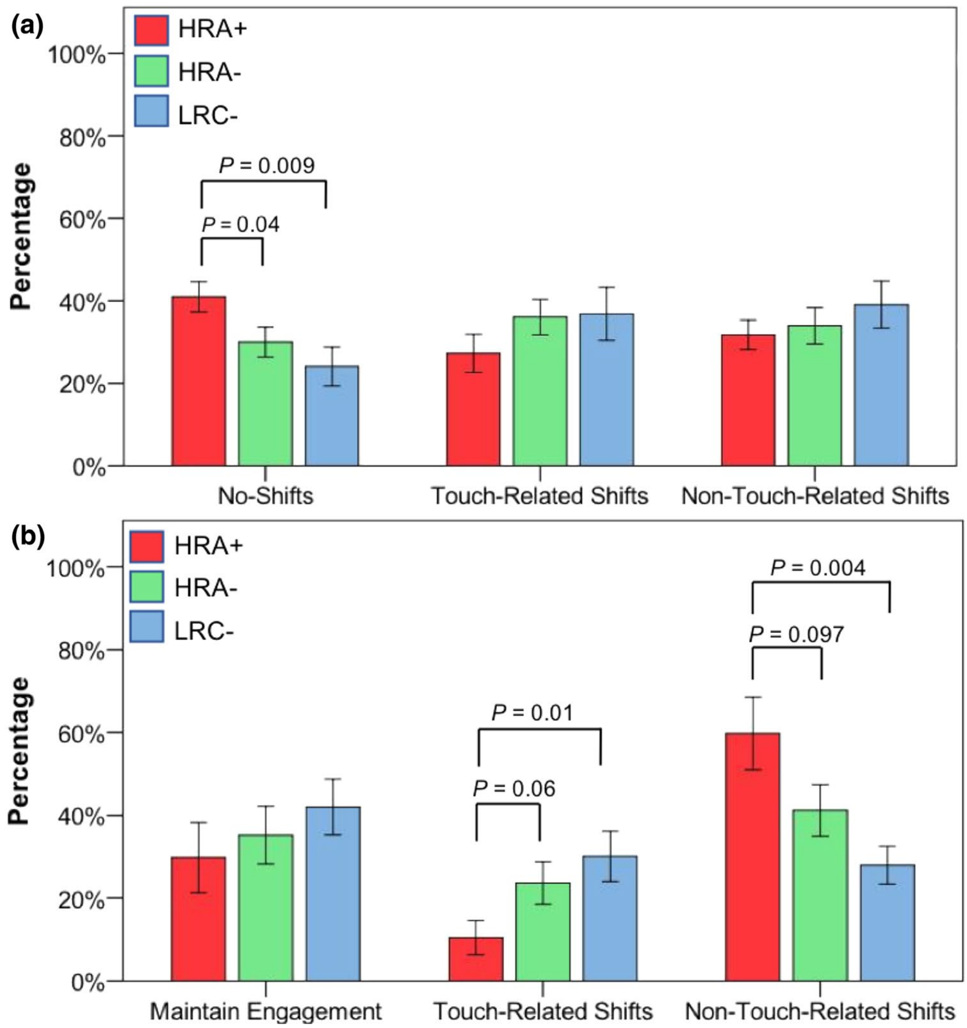

Fig. 2 Mean percentages of infant response types to caregiver touches among HRA+, HRA− and LRC− groups in the non-lead-in (**a**) and lead-in categories (**b**) with error bars showing ± 1 standard error

Table 2 Regression analysis of ADOS severity and mullen verbal DQ scores at outcome for HRA infants

Outcome	Predictor	*β*	*t*	*p*
ADOS severity scores[a]	No-shift in non-lead-ins	8.42	2.29	0.03*
	Touch-related shifts in lead-ins	−3.33	−1.08	0.28
	Non-touch-related shifts in lead-ins	1.67	0.88,	0.39
Mullen verbal DQ scores[b]	No-shift in non-lead-ins	−6.88	−0.27	0.79
	Touch-related shifts in lead-ins	12.99	0.60	0.55
	Non-touch-related shifts in lead-ins	−14.21	−1.07	0.29

[a]$R^2=.308$, $F(3, 22)=3.27$, $p=0.04$*

[b]$R^2=.102$, $F(3, 22)=0.84$, $p=0.48$

*$p<0.05$

of Maintaining Engagement responses during Lead-Ins, $F(2,36)=0.68$, $p=0.51$, $\eta_p^2=0.04$, however, there were significant group differences in percentage for both Touch-Related $F(2,36)=3.82$, $p=0.03$, $\eta_p^2=0.17$, and Non-Touch-Related Shifts, $F(2,36)=5.53$, $p=0.008$, $\eta_p^2=0.24$. Follow-up independent samples t-tests showed that HRA+ infants had a significantly lower percentage of Touch-Related Shifts (10%) compared to LRC− infants (30%, $t(24)=-2.67$, $p=0.01$, $d=1.06$) and marginally significantly lower Touch-Related Shifts compared to HRA− infants (24%, $t(24)=-2.01$, $p=0.06$, $d=0.85$). In contrast, HRA+ infants had a significantly higher percentage of Non-Touch-Related Shifts (60%) compared to LRC− infants (28%, $t(24)=3.22$, $p=0.004$, $d=1.20$) and a marginally higher percentage of Non-Touch-Related Shifts compared to HRA− infants (41%, $t(24)=1.73$, $p=0.097$, $d=0.66$) (Fig. 2b; Supplementary Table 3). This indicates that although infants in all groups maintained their attention to touch in the Lead-In category, when they did initiate an overt shift of attention, HRA+ infants were more likely to shift their attention away from that touch compared to HRA− and LRC− infants.

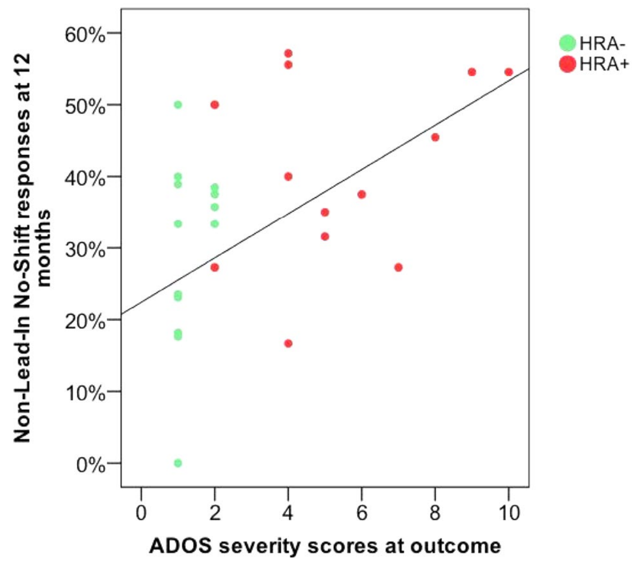

Fig. 3 ADOS severity scores at outcome as predicted by infants' percentages of No-Shift responses in the Non-Lead-In category at 12 months in the HRA group

12-Month Touch Responsivity as a Predictor of ASD Symptoms

For the HRA group, two multiple linear regressions were conducted to predict language skills and autism symptomatology based on percentage of No-Shifts in the Non-Lead-In category and Touch-Related and Non-Touch-Related shifts in the Lead-In category. Our first multiple linear regression examined whether No-Shifts in the Non-Lead-In category and Touch- and Non-Touch-Related shifts in the Lead-In category predict ADOS severity scores. A second regression analysis examined if the same three variables predict verbal DQ scores as measured by the MSEL at outcome. The results of the regressions indicated that touch responsivity at 12 months predicted ADOS severity scores, but not MSEL verbal DQ scores, at outcome in the HRA group (Table 2).

Specifically, the three predictors explained 30.8% of the variance in ADOS severity scores in the HRA group. No-shifts in the Non-Lead-In category significantly predicted ADOS severity scores (Fig. 3), whereas Touch-Related shifts and Non-Touch-Related shifts in the Lead-In category did not (Table 2).

Discussion

We examined overt attentional orienting to caregiver touches in 12-month-olds at high risk for ASD, and the relationship between early responsivity to caregiver touch and children's language skills and ASD symptomatology at outcome. Our results indicate that 12-month-olds later diagnosed with ASD (HRA +) are less likely to shift their attention in response to caregiver touch compared to LRC− and HRA− infants. In addition, infants in the HRA+ group show fewer Touch-Related and more Non-Touch-Related Shifts compared to the LRC− infants, indicating that HRA+ infants are more likely to direct their focus away from, rather than toward, any touch-related stimuli. Similarly, HRA+ infants show less responsivity to touch compared to HRA− infants, albeit at a marginally significant level. Finally, for the HRA group, the percentage of No-Shifts at 12 months, but not Lead-In Touch-Related and Non-Touch-Related shifts, significantly predicts ADOS severity scores at outcome. However, touch responsivity at 12 months is not predictive of language scores in the HRA group at outcome. We discuss three possible explanations that may account for this atypical responsivity to touch in infants later diagnosed with ASD.

First, our finding that infants later diagnosed with ASD are less likely to overtly shift their attention in response to touch extends prior reports of impaired social orienting in ASD to a new domain since previous reports of impaired social orienting have only been documented in response to visual (Baranek 1999; Swettenham et al. 1998) and auditory (Dawson et al. 2004) cues. This extension to touch makes sense within a framework in which ASD is characterized by a general impairment in attentional functioning (Keehn et al. 2013) and in which failure to rapidly shift attention between any stimuli may contribute to impairments in social orienting (Courchesne et al. 1994; Swettenham et al. 1998). Thus, our results indicating greater percentage of No-Shifts in the HRA+ infants may support a domain-general impairment in attentional orienting.

Second, increased No-Shift responses to touch in the HRA+ group may reflect early differences in social motivation (Chevallier et al. 2012; Dawson et al. 2004). According to the social motivation theory, individuals with ASD often find it difficult to form stimulus-reward contingencies for social stimuli, which may result in reduced attention directed towards such stimuli (Chevallier et al. 2012). Given that touch here is delivered in a social context, this is a plausible explanation for this result. Moreover, this argument is further supported by the finding that HRA+ infants showed greater Non-Touch-Related Shifts in Lead-In touch bouts. It is possible that infants in the HRA+ group may not have found such experiences to be inherently rewarding thereby choosing to orient their attention away from those interactions. Importantly, the frequency of specific touch types presented to infants did not differ across the three groups, suggesting that differences in infants' responsivity is unlikely to be attributed to the characteristics of specific types of maternal touches.

Third, although these findings are congruent with the hypotheses that young children with ASD show 'sticky attention' patterns (Elsabbagh et al. 2013; Zwaigenbaum et al. 2005) and lack of interest in social stimuli (Chevallier et al. 2012) in early development, they also raise the possibility that children with ASD have a more general impairment in processing sensory stimuli. In particular, young children with ASD have been shown to exhibit both hypo- and hyper-responsiveness to sensory stimuli, with hypo-responsiveness being more prevalent during early development (Baranek et al. 2006, 2013). In the present study, HRA+ infants were significantly less responsive to caregiver touch in the Non-Lead-In category potentially indicative of tactile hypo-responsivity. However, when HRA+ infants did respond to touch in the Lead-In category, they were more likely to orient their attention away from that interaction compared to infants in the other groups suggesting that they may be hyper-responsive (e.g., aversion/avoidance) to caregiver touch.

Additionally, our findings indicate that increased no-shift responses in the Non-Lead-In category, but not Touch-Related or Non-Touch-Related shifts in the Lead-In category, can reliably predict ADOS severity scores in HRA infants at outcome. These results are consistent with prior research suggesting that hypo-responsiveness to sensory stimuli is characteristic of young children with ASD in social contexts (Baranek et al. 2006). In particular, we found a positive correlation between percentage of No-Shifts in the Non-Lead-In category and ADOS severity scores in HRA infants at outcome, suggesting that infants who had greater No-Shifts had increased ASD symptomatology. These results support findings by Cascio et al. (2018) and Foss-Feig et al. (2012) and suggest that deficits in attending to touch may be associated with impaired social interaction in ASD and indicate that this relationship may be evident early in development. Thus, any deficit in attending to touch in infants may be detrimental for later socio-communicative development. However, it still remains unclear whether this atypical responsivity to touch is a result of an impairment in attending to tactile stimuli and how this may contribute to the heterogeneous nature of social-communicative deficits observed in ASD. Future research should examine the neural and behavioral indices of touch-related attentional capture to social and non-social stimuli and how tactile responsiveness relates to socio-communicative impairments in ASD. Examining touch responsivity in both social and non-social domains may help to adjudicate between theories of domain-general attentional deficits and domain-specific deficits in social motivation.

Lastly, since attention to touch may affect speech perception and early vocabulary development in infants (Abu-Zhaya et al. 2017; Seidl et al. 2015), we examined the association between touch responsivity and later language in the HRA group. Our findings indicate that, touch responsivity is not predictive of language skills at outcome. This may be the result of the specific outcome measure used. The MSEL assesses children's use of language during the testing period and does not provide us with information regarding the child's overall vocabulary. Further, some have argued that children's motivation, attention and test-taking skills may contribute to their language scores in such structured tasks (Condouris et al. 2003). Using parental assessment of children's early vocabulary, thus, might provide us with a measure that looks at children's language abilities as observed in naturalistic settings. Additionally, prior research examining the role of touch suggests that children's early vocabularies may include words that are frequently associated with caregiver touches (Abu-Zhaya et al. 2017; Nomikou and Rohlfing 2011). Therefore, future work should explore the relation between touch responsivity and children's later vocabulary levels to examine the role of touch in word learning abilities.

The current study is not without limitations. In particular, our results should be considered preliminary given our sample size. While relatively small, the current sample was selected to be well matched based on caregiver touches to avoid potential confounds that may occur between infant responsivity and touch frequency. Specifically, a major concern is that the total amount of touches presented to infants could differ and thus affect infants' responsivity. For example, given that individuals with ASD often show hypo-responsiveness to surrounding stimuli (Baranek et al. 2013), it is possible that caregivers with HRA+ infants provide more touches to their infants to elicit a social response. Alternatively, infants who are hyper-responsive to touch may receive overall less touches by their caregivers. Matching based on touch bouts therefore, allowed us to control for the opportunities that each participant received to respond to touch. In addition, it is important to acknowledge that our HRA− group had a higher Mullen ELCS score at 12 months compared to HRA+ and LRC− groups, which may have been a factor of how these infants responded to maternal touch. Nonetheless, there were no differences in Mullen ELCS scores between HRA+ and LRC− infants; groups which yielded significant differences in touch responsivity.

In conclusion, our findings show that HRA+ infants are less responsive to caregiver touch compared to LRC− infants and that when they do respond, they may orient away from touch. This work also reveals that non-responsiveness to caregiver-touch at 12 months can predict ADOS severity scores at outcome for infants in the HRA group. Thus, examining reduced responsivity to caregiver touch may be helpful in future research that aims to study early behavioral markers in infants at high risk for ASD.

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Author Contributions GK, BK and AS contributed to data analysis and manuscript writing. HTF and CAN are the principal investigators of the larger Infant Sibling Project and contributed to data analysis and manuscript revisions. All authors read and approved the final version of the manuscript.

Compliance with Ethical Standards

Conflict of interest The authors declare that they have no conflict of interest.

Informed Consent Informed consent was obtained from all individual participants included in the study.

Research Involving Human Participants and/or Animals All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. This article does not contain any studies with animals performed by any of the authors.

References

Abu-Zhaya, R., Seidl, A., & Cristia, A. (2017). Multimodal infant-directed communication: How caregivers combine tactile and linguistic cues. *Journal of Child Language, 44*(5), 1088–1116.

American Psychiatric Association. (2013). *DSM 5*. American Psychiatric Association.

Baranek, G. T. (1999). Autism during infancy: A retrospective video analysis of sensory-motor and social behaviors at 9–12 months of age. *Journal of Autism and Developmental Disorders, 29*(3), 213–224.

Baranek, G. T., & Berkson, G. (1994). Tactile defensiveness in children with developmental disabilities: Responsiveness and habituation. *Journal of Autism and Developmental Disorders, 24*(4), 457–471.

Baranek, G. T., Foster, L. G., & Berkson, G. (1997). Tactile defensiveness and stereotyped behaviors. *American Journal of Occupational Therapy, 51*(2), 91–95.

Baranek, G. T., David, F. J., Poe, M. D., Stone, W. L., & Watson, L. R. (2006). Sensory Experiences Questionnaire: Discriminating sensory features in young children with autism, developmental delays, and typical development. *Journal of Child Psychology and Psychiatry, 47*(6), 591–601.

Baranek, G. T., Watson, L. R., Boyd, B. A., Poe, M. D., David, F. J., & McGuire, L. (2013). Hyporesponsiveness to social and nonsocial sensory stimuli in children with autism, children with developmental delays, and typically developing children. *Development and Psychopathology, 25*(2), 307–320.

Brugman, H. & Russel, A. (2004). Annotating multimedia/multi-modal resources with ELAN. In *Proceedings of LREC 2004, Fourth International Conference on Language Resources and Evaluation*. The Language Archive, Max Planck Institute for Psycholinguistics Online, Nijmegen. http://tla.mpi.nl/tools/tla-tools/elan/.

Cascio, C. J., Moore, D., & McGlone, F. (2018). Social touch and human development. *Developmental Cognitive Neuroscience, 35,* 5–11.

Cesaroni, L., & Garber, M. (1991). Exploring the experience of autism through firsthand accounts. *Journal of Autism and Developmental Disorders, 21*(3), 303–313.

Chevallier, C., Kohls, G., Troiani, V., Brodkin, E. S., & Schultz, R. T. (2012). The social motivation theory of autism. *Trends in Cognitive Sciences, 16*(4), 231–239.

Condouris, K., Meyer, E., & Tager-Flusberg, H. (2003). The relationship between standardized measures of language and measures of spontaneous speech in children with autism. *American Journal of Speech-Language Pathology, 12*(3), 349–358.

Courchesne, E., Chisum, H., & Townsend, J. (1994). Neural activity-dependent brain changes in development: Implications for psychopathology. *Development and Psychopathology, 6*(4), 697–722.

Dawson, G., Meltzoff, A. N., Osterling, J., Rinaldi, J., & Brown, E. (1998). Children with autism fail to orient to naturally occurring social stimuli. *Journal of Autism and Developmental Disorders, 28*(6), 479–485.

Dawson, G., Toth, K., Abbott, R., Osterling, J., Munson, J., Estes, A., et al. (2004). Early social attention impairments in autism: Social orienting, joint attention, and attention to distress. *Developmental Psychology, 40*(2), 271.

Dunbar, R. I. (2010). The social role of touch in humans and primates: Behavioural function and neurobiological mechanisms. *Neuroscience and Biobehavioral Reviews, 34*(2), 260–268.

Elsabbagh, M., Fernandes, J., Webb, S. J., Dawson, G., Charman, T., Johnson, M. H., et al. (2013). Disengagement of visual attention in infancy is associated with emerging autism in toddlerhood. *Biological Psychiatry, 74*(3), 189–194.

Field, T. (2001). *Touch*. Cambridge: A Bradford Book.

Foss-Feig, J. H., Heacock, J. L., & Cascio, C. J. (2012). Tactile responsiveness patterns and their association with core features in autism spectrum disorders. *Research in autism spectrum disorders, 6*(1), 337–344.

Gallace, A., & Spence, C. (2010). The science of interpersonal touch: An overview. *Neuroscience and Biobehavioral Reviews, 34*(2), 246–259.

Gotham, K., Risi, S., Pickles, A., & Lord, C. (2007). The Autism Diagnostic Observation Schedule: Revised algorithms for improved diagnostic validity. *Journal of Autism and Developmental Disorders, 37*(4), 613.

Gottlieb, G. (1971). Ontogenesis of sensory function in birds and mammals. In E. Tobach, L. R. Aronson, & E. Shaw (Eds.), *The* *biopsychology of development* (pp. 67–128). New York: Academic Press.

Hertenstein, M. J. (2002). Touch: Its communicative functions in infancy. *Human Development, 45*(2), 70–94.

Hertenstein, M. J., Verkamp, J. M., Kerestes, A. M., & Holmes, R. M. (2006). The communicative functions of touch in humans, nonhuman primates, and rats: A review and synthesis of the empirical research. *Genetic, Social, and General Psychology Monographs, 132*(1), 5–94.

Hilton, C. L., Harper, J. D., Kueker, R. H., Lang, A. R., Abbacchi, A. M., Todorov, A., et al. (2010). Sensory responsiveness as a predictor of social severity in children with high functioning autism spectrum disorders. *Journal of Autism and Developmental Disorders, 40*(8), 937–945.

Ibanez, L. V., Messinger, D. S., Newell, L., Lambert, B., & Sheskin, M. (2008). Visual disengagement in the infant siblings of children with an autism spectrum disorder (ASD). *Autism, 12*(5), 473–485.

Kaiser, M. D., Yang, D. Y. J., Voos, A. C., Bennett, R. H., Gordon, I., Pretzsch, C., et al. (2015). Brain mechanisms for processing affective (and nonaffective) touch are atypical in autism. *Cerebral Cortex, 26*(6), 2705–2714.

Keehn, B., Müller, R. A., & Townsend, J. (2013). Atypical attentional networks and the emergence of autism. *Neuroscience and Biobehavioral Reviews, 37*(2), 164–183.

Leekam, S. R., Nieto, C., Libby, S. J., Wing, L., & Gould, J. (2007). Describing the sensory abnormalities of children and adults with autism. *Journal of Autism and Developmental Disorders, 37*(5), 894–910.

Lord, C., Risi, S., Lambrecht, L., Cook, E. H., Leventhal, B. L., DiLavore, P. C., et al. (2000). The Autism Diagnostic Observation Schedule—Generic: A standard measure of social and communication deficits associated with the spectrum of autism. *Journal of Autism and Developmental Disorders, 30*(3), 205–223.

Lovaas, O. I., Koegel, R. L., & Schreibman, L. (1979). Stimulus overselectivity in autism: A review of research. *Psychological Bulletin, 86*(6), 1236.

Maurer, D., & Maurer, C. (1988). *The world of the newborn*. New York: Basic Books.

Messinger, D., Young, G. S., Ozonoff, S., Dobkins, K., Carter, A., Zwaigenbaum, L., et al. (2013). Beyond autism: A baby siblings research consortium study of high-risk children at three years of age. *Journal of the American Academy of Child and Adolescent Psychiatry, 52*(3), 300–308.

Minshew, N. J., & Hobson, J. A. (2008). Sensory sensitivities and performance on sensory perceptual tasks in high-functioning individuals with autism. *Journal of Autism and Developmental Disorders, 38*(8), 1485–1498.

Mullen, E. M. (1995). *Mullen scales of early learning* (pp. 58–64). Circle Pines, MN: AGS.

Munson, J., Dawson, G., Sterling, L., Beauchaine, T., Zhou, A., Koehler, E., et al. (2008). Evidence for latent classes of IQ in young children with autism spectrum disorder. *American Journal on Mental Retardation, 113*(6), 439–452.

Nomikou, I., & Rohlfing, K. J. (2011). Language does something: Body action and language in maternal input to three-month-olds. *IEEE Transactions on Autonomous Mental Development, 3*(2), 113–128.

Rutter, M., Bailey, A., & Lord, C. (2003). *The social communication questionnaire: Manual*. Los Angeles: Western Psychological Services.

Sacrey, L. A. R., Bryson, S. E., & Zwaigenbaum, L. (2013). Prospective examination of visual attention during play in infants at high-risk for autism spectrum disorder: A longitudinal study from 6 to 36 months of age. *Behavioural Brain Research, 256,* 441–450.

Seidl, A., Tincoff, R., Baker, C., & Cristia, A. (2015). Why the body comes first: Effects of experimenter touch on infants' word finding. *Developmental Science, 18*(1), 155–164.

Siegel, B. (2004). *The pervasive developmental disorders screening Test-II (PDDST-II)*. California: University of California.

Stack, D. M., & Muir, D. W. (1992). Adult tactile stimulation during face-to-face interactions modulates five-month-olds' affect and attention. *Child Development, 63*(6), 1509–1525.

Swettenham, J., Baron-Cohen, S., Charman, T., Cox, A., Baird, G., Drew, A., et al. (1998). The frequency and distribution of spontaneous attention shifts between social and nonsocial stimuli in autistic, typically developing, and nonautistic developmentally delayed infants. *The Journal of Child Psychology and Psychiatry and Allied Disciplines, 39*(5), 747–753.

Volkmar, F. R. (2011). Understanding the social brain in autism. *Developmental Psychobiology, 53*(5), 428–434.

Walker, K., & Armstrong, L. (1995). Do mothers and fathers interact differently with their child or is it the situation which matters? *Child: Care, Health and Development, 21*(3), 161–181.

Weiss, S. J., Wilson, P., Hertenstein, M. J., & Campos, R. (2000). The tactile context of a mother's caregiving: Implications for attachment of low birth weight infants☆. *Infant Behavior and Development, 23*(1), 91–111.

Zwaigenbaum, L., Bryson, S., Rogers, T., Roberts, W., Brian, J., & Szatmari, P. (2005). Behavioral manifestations of autism in the first year of life. *International Journal of Developmental Neuroscience, 23*(2), 143–152.

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