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BRIEF REPORT

Caregiver Touch-Speech Communication and Infant Responses in 12-Month-Olds at High Risk for Autism Spectrum Disorder

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Abstract
Multimodal communication may facilitate attention in infants. This study examined the presentation of caregiver touch-only and touch + speech input to 12-month-olds at high (HRA) and low risk for ASD. Findings indicated that, although both groups received a greater number of touch + speech bouts compared to touch-only bouts, the duration of overall touch that overlapped with speech was significantly greater in the HRA group. Additionally, HRA infants were less responsive to touch-only bouts compared to touch + speech bouts suggesting that their mothers *may* use more touch + speech communication to elicit infant responses. Nonetheless, the exact role of touch in multimodal communication directed towards infants at high risk for ASD warrants further exploration.

Keywords Infant siblings · Autism · Touch · Multimodal input · Social orienting

Introduction

Infant-directed communication is by default a combination of visual (caregivers' facial expressions/gestures), tactile (caregiver touch), and auditory (caregiver speech) input directed to the child (Gogate et al. 2000; Meltzoff and Kuhl 1994) with redundancy across modalities (Gogate et al. 2001). For example, while showing a novel object to their infants, caregivers synchronize their input by naming and moving the object concurrently (Gogate et al. 2000, 2001). Such redundant sensory signals have been shown to recruit attention (Bahrick et al. 2004) and facilitate learning (Bahrick and Lickliter 2000). Therefore, differences in the presentation of the multimodal input, as well as deficits in multisensory integration may impact the early development of communication skills.

Children with autism spectrum disorder (ASD) show hyper- and/or hypo-responsiveness to sensory cues in their surroundings (Baranek et al. 2006), which may affect processing of multimodal sensory information. Because social events are often multimodal in nature and provide a greater number of intersensory redundancies compared to non-social events, deficits in processing multimodal information may contribute to the development of socio-communicative impairments in individuals with ASD (Bahrick 2010). For example, auditory perception of syllable sounds appear to be less influenced in children with ASD by the addition of mismatched visual information during the McGurk task (McGurk and MacDonald 1976) where a listener typically perceives an auditory signal as "da" as a result of *seeing* the speaker utter the syllable "ga" while simultaneously *hearing* the syllable "ba" (Irwin et al. 2011; Zhang et al. 2019). Furthermore, these impairments in audio-visual integration are associated with increased ASD symptomatology (Mongillo et al. 2008). Since caregivers show sensitivity to their child's sensory experience (e.g., Bergeson et al. 2006), atypical sensory responsivity in ASD may impact caregivers' use of

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multimodal cues during social interactions (Saint-Georges et al. 2011; Wan et al. 2012). For example, caregivers of infants who later receive a diagnosis of ASD use greater amounts of touch during social interactions compared to typically developing infants (Saint-Georges et al. 2011). However, it is unknown whether caregivers of high-risk infants (HRA) are more likely to provide multiple sensory cues, and whether their infants are hyper- and/or hypo-responsive to this sensory information.

Touch is of particular interest, since it plays a vital role in human interactions and facilitates early caregiver-infant communication (Dunbar 2010; Hertenstein et al. 2006). For instance, a greater amount of maternal affectionate touch in early typical development is associated with an increase in infant smiles and vocalizations (Stack and Muir 1992) and also predicts later cognitive and neurobehavioral development in preterm infants (Feldman and Eidelman 2003). Additionally, touch has also been shown to facilitate early language development in infants (Abu-Zhaya et al. 2017; Nomikou and Rohlfing 2011; Seidl et al. 2015). For example, infants' early vocabularies are often words associated with their caregivers' touches, and touch, when integrated with speech, can facilitate speech perception in multimodal interactions (Abu-Zhaya et al. 2017; Seidl et al. 2015) further emphasizing the importance of touch in early development.

The current study investigates the presentation of caregiver touch-only and touch + speech input to 12-month-olds at high and low risk for ASD. Specifically, we examine, (1) the frequency of all caregiver touches, (2) the percentage of touch that overlaps with speech, and (3) the percentage of touch-only and touch + speech bouts presented to 12-month-olds at high and low risk for ASD. Given that (1) early deficits in orienting to social information are present in children with ASD (Baranek 1999; Dawson et al. 2004; Swettenham et al. 1998), (2) HRA infants with a later diagnosis of ASD (HRA+) are overall less responsive to touch (Kadlaskar et al. 2019), and that (3) the impairments in social communication and visual orienting are often shown in siblings and relatives of individuals with ASD (Bishop et al. 2004; Elsabbagh et al. 2009), we predict that, caregivers in the HRA group may produce more tactile input, use greater percentage of touch that overlaps with speech, and deliver greater number of touch + speech bouts compared to touch-only bouts in order to elicit a response from their infants compared to caregivers of low-risk comparison (LRC) infants.

Furthermore, to understand whether any differences in the presentation of touch-only and touch + speech input are related to infants' responsivity, we examine infants' responsiveness to touch-only and touch + speech input. Since, presentation of multimodal input has been shown to garner attention in typical development (Bahrick and Lickliter 2000), we predict that LRC infants will be more responsive to touch + speech input compared to touch-only input. If multisensory information also captures attention in HRA infants, then touch + speech input will elicit more attentional shifts in the HRA group. However, if multimodal input does not facilitate attention in the HRA group, then there will be no differences in attentional shifts in response to touch + speech and touch-only input. Alternatively, if multisensory information is overstimulating, then touch + speech input may elicit more attention shifts away from touch in the HRA group. Lastly, given that caregivers are sensitive to their infants' sensory experiences (Bergeson et al. 2006; Wan et al. 2012) we predict that, caregiver patterns of producing touch + speech input will be correlated with infants' overall responsivity to tactile input in both HRA and LRC groups.

Methods

Participants

Data for 58 (31 HRA, 27 LRC-) 12-month-olds and their caregivers were randomly selected from a larger sample (N = 144) of infant-caregiver dyads that was obtained as a part of a prospective, longitudinal study. HRA infants were recruited through clinics at Boston Children's Hospital and community sources. LRC infants were recruited through lab registry and community sources. 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-2; 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.

HRA and LRC groups did not differ on demographic variables or infants' Early Learning Composite Scores (ELCS) on the Mullen Scales of Early Learning (MSEL: Mullen 1995) Table 1).

Procedure

Twelve-month-olds participated in a 10-min video-taped free-play session in the lab with their mothers. All dyads were provided with an identical set of age-appropriate toys (e.g., book, ball, toy vehicles, etc.) and were instructed to

Table 1 Participant demographics at 12 months

	HRA	LRC	Statistic	*p* value
N (male)	31 (17)	27 (12)	X^2 (1) = .63	.43
Age (days)	376.7 (11.69), 359–413	375.2 (10.57), 360–396	$t(56) = -.51$	.61
MSEL ELCS	100.68 (18.46), 70–138	106.89 (15.39), 77–134	$t(56) = 1.37$	.17
MSEL receptive language	42 (9.28), 25–55	46.33 (8.84), 25–64	$t(56) = -1.81$	.07
MSEL expressive language	47.52 (14.12), 20–78	50.19 (9.75), 37–71	$t(56) = -.82$	.41
%Mothers with 4-year college degree or higher	70.37	91.30	X^2 (1) = 3.64	.06
%Fathers with 4-year college degree or higher	77.78	82.61	X^2 (1) = .18	.67
Family income (% with income greater than 65,000)	92.59	85	X^2 (1) = .69	.41

Mean (SD), range

play as they would in any other natural setting. The study protocol was approved by the Institutional Review Boards of Boston University and Boston Children's Hospital and informed consent was obtained from the parent(s) of each infant participant.

Observational Measures

Caregiver Touch

Video coding of maternal touches and infant responses to touches was performed using ELAN software (Brugman et al. 2004). A total of 14 trained research assistants, in teams of two, who were blind to group membership, evaluated the frequency, type, and location of mother-initiated intentional touches delivered to infants during free-play (e.g., a tap on the infant's leg with a toy; Fig. 1a). In order to become reliable, all research assistants were required to obtain a minimum reliability score of $r = .80$ on a test video. Intentional touch was defined as any touch that appeared to be deliberately initiated by the mother. Accidental touches (e.g., accidentally brushing the infant's shoulder while reaching for a ball) were not coded. Coding of maternal touches was based on the touch coding scheme used by Abu-Zhaya et al. (2017). (See Supplementary Materials Table 1 and Appendix A for additional analysis of touch types).

Caregiver Speech

After coding maternal touches, an audio file of the interaction was imported to Praat software (Boersma and Weenink 2019). A trained coder, blind to group membership, coded maternal speech utterances that occurred during each touch bout as well as all utterances that began within one second before and after each touch (Fig. 1a). An utterance was defined as a syntactic unit (sentence or a phrase) separated by a pause (0.5 s or longer) or a pitch reset from any adjacent unit. Pitch resets were analyzed by examining the pitch tracker in the spectrogram window of Praat software.

After coding speech, first we calculated the percentage of total touch duration that overlapped with speech for each child (Fig. 1b). This percentage was calculated by dividing the total duration of speech *during* touch bouts by the *total* duration of all touch bouts. Next, we categorized touch bouts into touch-only or touch + speech bouts. Touch-only bouts were defined as touch bouts that did not overlap with speech whereas, touch + speech bouts were defined as touch bouts that did overlap with speech (Fig. 1a). The percentage of touch-only and touch + speech bouts was calculated by separately dividing the total number touch-only and touch + speech bouts by the total number of all touch bouts (Fig. 1b). Note that the percentage of touch-only and touch + speech bouts refers only to the *number* of touch-only and touch + speech bouts, whereas, the percentage of overlap between touch and speech refers to the *duration* of all touch that overlaps with speech.

Infant Responsivity to Touch-Only and Touch + Speech Bouts

Maternal touches were used as a reference to code infants' responses in ELAN (Brugman et al. 2004). Infants' looking behaviors before, during, and after a touch were coded by examining infants' eye gaze and/or head movements (Fig. 1a). Infant responses were analyzed only in interactions where the infant was *not* already attending to any of the touch-related stimuli or locations prior to the touch (e.g., we excluded cases where the infant was looking at the mother's hand, object of focus or the mother's face before the mother delivered a touch). Infants' post-touch looking behaviors were divided into Touch-Related, Non-Touch-Related, and No-Shift responses. For example, if following a touch, the infant shifted her attention to the caregiver (e.g., her face), a touch-related object (object held in mother's hand), or the touch location (e.g., infant's leg) this was classified as Touch-Related. If the infant shifted her attention to an object not involved in the touch, then this was classified as a Non-Touch-Related response. Lastly, if the infant did not shift her

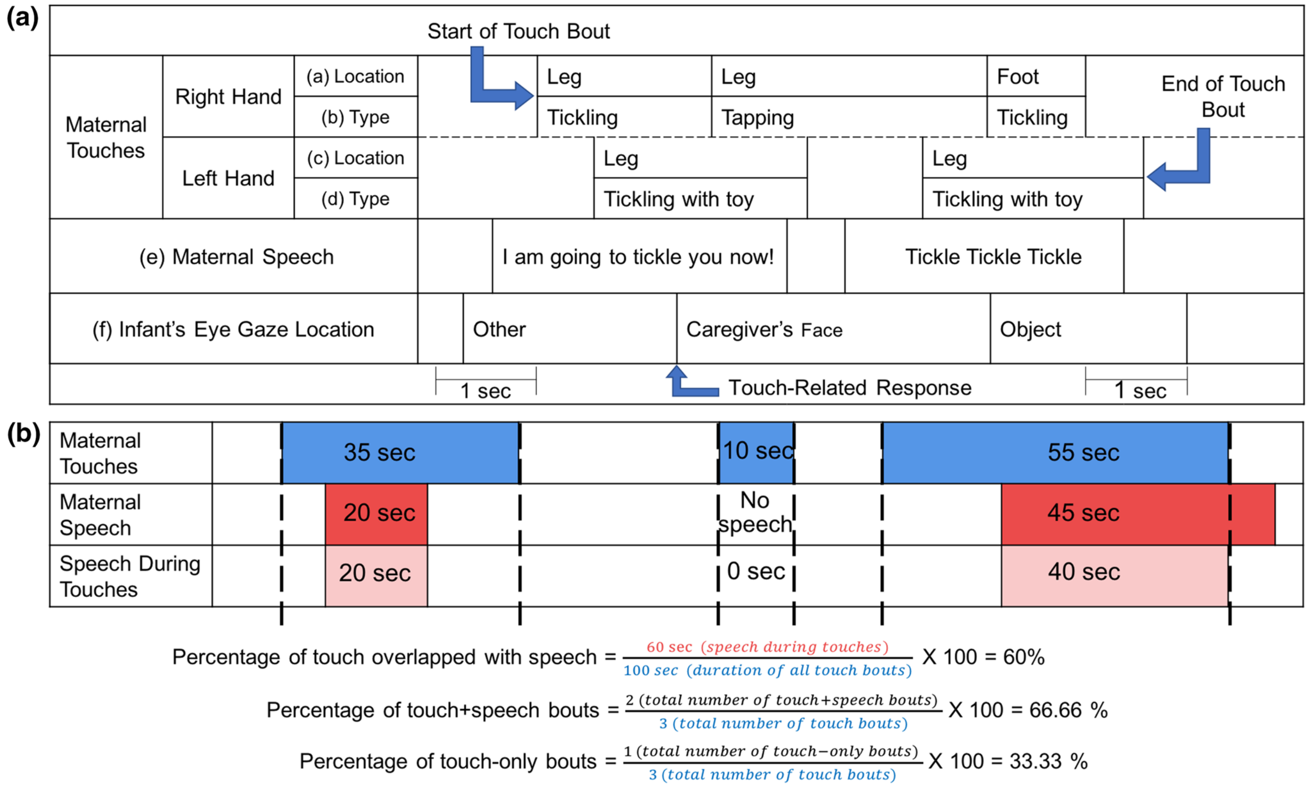

Fig. 1 **a** Illustration of a touch + speech bout. Tiers a, b, c and d show caregiver touches and types delivered by right and left hands respectively. Single touches were combined into touch bouts defined as simultaneous touch events delivered by both hands or consecutive touch events presented by either one or both hands that occurred within 1 s of each other. Tier e shows maternal speech that starts within the window of 1 s before and after each touch bout. Tier f shows infants' attentional shifts before, during and after each touch bout. **b** Illustration of caregiver input with two touch + speech and one touch-only bout

attention, then this was classified as a no-shift response (i.e., a non-response). Infants who received fewer than 5 touch bouts (n = 3; 2 HRA, 1 LRC) were excluded before analyzing infant responsivity to touch-only and touch + speech bouts. Inter-rate reliability was obtained by calculating Pearson's correlations for each variable and was found to be high (see Supplementary Materials for more details).

Results

Independent samples t-tests were conducted to examine: (1) the frequency of touch bouts, (2) the percentage of total touch that overlapped with speech, and (3) the percentages of touch-only and touch + speech bouts between the two groups (HRA, LRC).

Results revealed a marginally significant difference for touch bout frequency between the HRA (M = 19.87, SD = 9.30) and LRC groups (M = 16.19, SD = 6.36), $t(56) = 1.74$, $p = .08$, $d = .46$. The total duration of these touches did not differ between the HRA (M = 113.41 s, SD = 95.85 s) and LRC (M = 103.04 s, SD = 65.45 s) groups, $t(56) = .474$, $p = .64$, $d = .12$. Second, for the percentage of total touch that overlapped with speech, caregivers in the HRA group produced significantly greater overlap (42.4%) compared to caregivers in the LRC (34.6%) group, $t(56) = 2.21$, $p = .03$, $d = .58$. Third, despite greater touch and speech overlap in the HRA group, there were no significant differences in the percentages of touch + speech bouts between HRA (79%) and LRC (75%) groups, $t(56) = 1.09$, $p = .27$, $d = .34$. In sum, although both groups were exposed to similar numbers of touch + speech bouts, the total percentage of touch that overlapped with speech differed between the two groups. Lastly, the percentage of touch + speech bouts was greater compared to touch-only bouts for both HRA $t(30) = 14.31$, $p < .001$, $d = 2.56$ and LRC groups $t(26) = 7{,}28$, $p < .001$, $d = 1.40$ (79% and 75% touch + speech vs. 21%, 25% touch-only bouts in HRA and LRC groups, respectively).

Exploratory Analysis

A series of exploratory analyses examined whether caregivers from each group might produce a greater number of touch + speech bouts because infants were more responsive to multimodal input. Specifically, for each Shift Type (Touch-Related, Non-Touch-Related, No-Shifts), we ran a 2×2 ANOVA with Group (HRA, LRC) as a between-subject factor and Bout Type (touch-only, touch + speech) as a within-subjects factor.

Touch-Related Shifts

There was a main effect of Bout Type, $F(1, 40) = 7.93$, $p = .01$, $\eta_p^2 = .16$, as the percentage of Touch-Related shifts was greater in response to touch + speech bouts (36%) compared to touch-only bouts (21%). However, there was no main effect of Group, $F(1, 40) = .04$, $p = .84$, $\eta_p^2 = .00$, or interaction between Bout Type and Group, $F(1, 40) = .21$, $p = .64$, $\eta_p^2 = .01$.

Non-touch-Related Shifts

There was no main effect of Bout Type, $F(1, 40) = 1.78$, $p = .19$, $\eta_p^2 = .04$, or Group, $F(1, 40) = 2.25$, $p = .14$, $\eta_p^2 = .05$. However, there was a significant interaction between Bout Type and Group, $F(1, 40) = 6.05$, $p = .02$, $\eta_p^2 = .13$, suggesting that infants differed in the percentages of Non-Touch-Related shifts in touch-only and touch + speech bouts depending on group membership. Follow-up paired-samples t-tests revealed that, in the LRC group, Non-Touch-Related shifts were significantly greater in response to touch-only (52%) compared to touch + speech (31%) bouts, $t(17) = 2.29$, $p = .03$, $d = .53$, whereas infants in the HRA group showed similar percentages of Non-Touch-related shifts in response to touch-only (29%) and touch + speech (35%) bouts, $t(23) = -.93$, $p = .36$, $d = .18$. Independent-samples t-tests showed that, for Non-Touch-Related shifts, groups differed significantly for touch-only (LRC = 54%; HRA = 29%), $t(41) = -2.67$, $p = .01$, $d = .81$, but not touch + speech bouts (LRC = 32%; HRA = 34%), $t(52) = .27$, $p = .79$, $d = .09$. Thus, LRC infants were more likely to orient away from touch-only bouts than HRA infants. However, there were no differences in Non-Touch-Related shifts to touch + speech bouts between the two groups.

No-Shifts

There was no significant main effect of Bout Type, $F(1, 40) = 2.12$, $p = .15$, $\eta_p^2 = .05$ or Group, $F(1, 40) = 2.92$, $p = .095$, $\eta_p^2 = .07$, but there was a marginal interaction between Bout Type and Group, $F(1, 40) = 3.43$, $p = .07$, $\eta_p^2 = .08$. Follow-up paired-samples t-tests revealed that, in the HRA group, No-Shifts were greater in response to touch-only bouts (48.4%) compared to touch + speech (28.9%) bouts $t(23) = 2.58$, $p = .02$, $d = .51$, whereas the LRC group showed similar percentages of No-Shifts in response to touch-only (27.3%) and touch + speech (29.6%) bouts, $t(17) = -.26$, $p = .79$, $d = .06$. Follow-up independent-samples t-tests revealed that, for touch-only events, infants in the HRA group showed significantly greater percentages of No-Shifts (48%) compared to infants in the LRC (25%) group, $t(41) = 2.34$, $p = .02$, $d = .76$, but percentages of No-Shifts were not significantly different to touch + speech bouts between HRA (29%) and LRC (30%) groups $t(52) = -.03$, $p = .98$, $d = .01$, suggesting that HRA infants were more likely to fail to orient their attention to touch-only (but not touch + speech) bouts compared LRC infants (see Table 2; 3 in Supplementary Materials for visual representation of independent-samples t-tests).

Correlations Between Percentage of Touch + Speech Bouts and Infant Responsivity

Pearson correlations were calculated to examine, whether the percentage of touch + speech bouts was related to infants' responsivity to touch. For all infants, the percentage of touch + speech bouts was not significantly associated with Touch-Related ($r(55) = .21$, $p = .12$), Non-Touch-Related ($r(55) = -.17$, $p = .21$) and No-Shift responses ($r(55) = -.05$, $p = .72$) (see Table 4 in Supplementary Materials). However, in the HRA group, the percentage of touch + speech bouts was negatively correlated with No-Shifts, $r(29) = -.39$, $p = .03$, indicating that infants in the HRA group were less likely to show No-Shifts when they received a higher percentage of touch + speech bouts (Fig. 2). Finally, in the LRC group, the percentage of touch + speech bouts was negatively correlated with Non-Touch-Related shifts, $r(26) = -.42$, $p = .03$, indicating that, LRC infants were less likely to shift attention to non-touch-related objects when they received a greater percentage of touch + speech input.

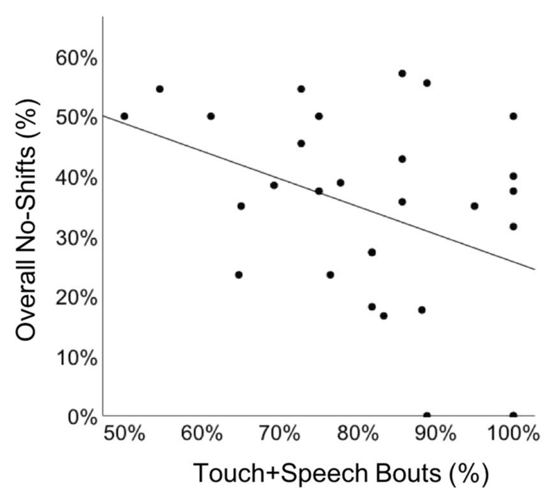

Fig. 2 Percentage of overall No-Shifts in response to tactile input and percentage of touch + speech bouts in the HRA group

Discussion

The current study examined the presentation of caregiver touch-only and touch + speech input to 12-month-olds at high and low risk for ASD. Specifically, we examined, (1) the frequency of all caregiver touches, (2) percentage of touch that overlapped with speech and (3) percentage of touch-only and touch + speech input presented to 12-month-olds at high and low risk for ASD. Our results indicated that infants in the HRA group received a marginally greater number of touches compared to infants in the LRC group. This marginal result warrants exploration in a larger sample. Second, infants in the HRA group received greater percentage of touch input that overlapped with speech. A possible explanation for the greater overlap of touch with speech in the HRA group could be attributed to strategies that mothers draw from their experiences of interacting with their older child with ASD. For example, a large body of research has shown that children with, and at high risk for, ASD have deficits in social orienting (Bhat et al. 2010; Dawson et al. 2004; Swettenham et al. 1998) and that HRA infants who later receive a diagnosis of ASD are less responsive to caregiver tactile input (Kadlaskar et al. 2019). Thus, it is reasonable to argue that mothers may be consciously or unconsciously providing greater amounts of multimodal input to their younger child aimed at increasing social orienting. Additionally, these findings concerning the amount of maternal tactile input cannot be merely attributed to infants' receptive and expressive language skills as the two groups did not differ in their language skills at 12 months.

We also found that infants in both the groups received a greater percentage of touch + speech bouts than touch-only bouts. This finding concerning the high percentages of touch + speech input is consistent with prior research indicating that caregiver-infant communication may be multimodal (Gogate et al. 2000) and suggests that, at least in the tactile modality, touches are often presented multimodally with speech in both the HRA and LRC groups. These findings extend previous reports of multimodal communication in the audio-visual modality (Gogate et al. 2000, 2015; Meyer et al. 2011) to a relatively understudied modality of audio-tactile interactions. Nonetheless, researchers examining multimodal communication in the audio-visual modality have mainly studied speech with gestures, which are always used as communicative tools (Gogate et al. 2000, 2015), while touch may not always have a solely communicative intent (e.g., holding an infant up may support her position, but may also convey affect and a gentle reminder to the infant to engage her muscles). Therefore, more research is needed to examine how different touch types could be divided into communicative, non-communicative, and a combination of communicative + non-communicative touches depending on infants' perception of different touch types. Lastly, because prior research has shown that, touch when integrated with speech, may facilitate early vocabulary development and speech perception in typically developing infants (Abu-Zhaya et al. 2017; Nomikou and Rohlfing 2011; Seidl et al. 2015), future longitudinal studies could examine the association between touch + speech input received at 12 months and later vocabulary in children with ASD.

In our exploratory analyses we examined whether caregivers in both the groups might produce greater amounts of touch + speech bouts than touch-only bouts because infants were more responsive to multimodal input in the context of touch and speech. We hypothesized that if multimodal information captures attention, then infants in both the groups should show more Touch-Related-Shifts in response to touch + speech compared to touch-only input. Alternatively, if multimodal input does not facilitate attention, or if multisensory information is overstimulating in the HRA group, then there will be no differences in attentional shifts between touch-only and touch + speech bouts or touch + speech bouts may elicit more attention shifts *away* from touch (i.e., Non-Touch-Related-Shifts) in the HRA group. Results indicated that caregiver behavior may have been related to infant responsivity and that this varied by group membership. First, for both groups, Touch-Related shifts were greater in response to touch + speech compared to touch-only bouts, further supporting the argument that multimodal communication captures infant attention (Bahrick et al. 2004). Second, there were no differences in Non-Touch-Related shifts in response to touch + speech bouts between the HRA and LRC groups, nor were Non-Touch-Related shifts significantly more frequent to touch + speech versus touch-only bouts for HRA infants, indicating that multimodal input may not have been overstimulating to HRA infants. Third, HRA infants tended to respond less proportionally to touch-only compared with touch + speech combinations. Reduced responsivity to touch-only bouts in the HRA group is consistent with past evidence suggesting hypo-responsivity to single sensory stimuli (Baranek et al. 2013). This explanation is further supported by correlations between the percentage of touch + speech bouts and the percentage of No-Shifts in the HRA group. In other words, a greater percentage of touch + speech bouts was related to decreased percentages of No-Shifts in the HRA group. Thus, infants in the HRA group may show more attentional shifts to frequent touch + speech input compared to touch-only input, suggesting that the presentation of touch along with speech may facilitate orienting in infants at high risk for ASD. Nonetheless, it is important to acknowledge that, for the HRA group, although touch + speech bouts elicited more attentional shifts compared to touch-only bouts, these shifts were not always directed toward the person, location, or object associated with the touch. Another possibility underlying infants' reduced responsivity to touch-only compared to touch + speech input could be attributed to different functions of touch-only and touch + speech input. It is possible that mothers may use touch + speech input in order to elicit attention, whereas, touch-only input may not always have a solely communicative intent (e.g., holding without speech to support infant's position). Therefore, the perceived communicative capacity of touch + speech and touch-only input may impact infants' responsivity. Alternatively, certain types of touch-only input (e.g., tickling or tapping) may be perceived as unpleasant or intrusive affecting infants' responses. These findings warrant further exploration to determine the exact role of touch in multimodal input in typical and atypical development.

Last, our study is not without limitations. First, the majority of the mothers included in the present study were university graduates and families also fell within higher income brackets, which skewed our sample with respect to their socioeconomic status (SES). Specifically, the two groups showed no significant differences in family income, nonetheless, there was a marginal difference in the percentage of mothers who completed a 4-year-college degree. We know that, on average, caregivers from higher SES families interact more and use more diverse vocabulary and complex syntactic structures while communicating with their children compared to caregivers from lower SES families (Hoff 2003). If these SES-related behavioral patterns extend to the tactile modality, it is possible, that mothers in our sample may have used overall greater amounts or more diverse types of touch-only and touch + speech input while interacting with their infants compared to what might be observed in a lower SES sample. Thus, it is imperative to examine these same measures in a more diverse sample.

A second limitation is our relatively small sample size, which may make it challenging to examine more subtle effects of touch-only and touch + speech input as well as possible effects of different touch types to infants in both groups. Thus, future studies should explore infant responsivity using larger samples. Third, our study is limited in that we did not examine how the amount of maternal tactile input and infant responsivity to touch-only and touch + speech input relate to later ASD outcomes, and given that only a subsection of HRA infants will receive a later diagnosis of ASD, it is possible that maternal use of tactile input and infant responsivity could be impacted by tactile hypo- and/or hyper-responsivity that may be present at 12 months in this subsection of infants. Thus, studies with large sample sizes should examine how reactivity to touch-only and touch + speech input is related to HRA + and HRA- subgroups. Fourth, we elected to include all touch types in the present analysis as there does not yet exist empirical evidence indicating infants' *orienting* preferences to different types of touches (e.g., greater orienting to tickling/tapping vs. failure to orient to readjustments). However, it is possible that unique touch types (e.g., tickling, tapping) may be more likely to have communicative intent compared to others (e.g., readjustment touches). Future research can systematically explore mothers' use of different types of touches in both high- and low-risk infants, as well as infants' responsivity to different types of touches. Finally, we did not examine the amount of touch + speech bouts in comparison to speech-only bouts. Given the frequency of caregiver speech in most North American households (Bergelson et al. 2019) it is likely that the total amount of touch + speech bouts, although greater than touch-only bouts, may not be as frequent as speech-only input. Future research with larger datasets can examine maternal patters of using touch-only, speech-only, and touch + speech input in high and low-risk infants.

In sum, caregivers in both the HRA and LRC groups produce more touch + speech bouts compared to touch-only bouts while interacting with their infants. Because HRA infants are overall less responsive to touch-only bouts, their mothers may resort to using more touch + speech bouts aimed at eliciting greater number of infant responses. These findings have broader implications for caregiver-infant interactions in ASD, since providing a richer multimodal input has been suggested to promote learning and attention in typical development (Bahrick et al. 2004).

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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.

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