Can you find the buzzer?
The role of tactile stimulation in the development of body know-how.

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Abstract

Early sensorimotor experiences allow infants to learn new ways of combining cues concerning the body to develop a sense of their body and to best use the body to act on the environment or the body itself. Our hypothesis is that tactile stimulation has an important role in the development of reaching to the body. To explore this hypothesis, we followed the development of a group of 21 infants over a period from 4 to 8 months of age. The experimental group received weekly (non-social) tactile stimulation on their body, whereas the Control group was simply seen by the experimenter but did not receive tactile stimulation. Results showed that by 7 months, infants who received weekly tactile stimulation localized the buzzer on significantly more body areas and contacted the buzzer more frequently than controls. Thus, tactile stimulation facilitated the emergence of reaching to the body. What may be the mechanism that conveys this effect? We propose that externally provoked tactile stimulation gives the opportunity for infants to explore the sensory correlations emerging from this stimulation and to act on the impinging stimulus.

1. Introduction

Reaching to the body is performed habitually and supports adaptive behaviours such as removing foreign stimuli, scratching an itch or grooming. Despite its importance, only few studies have looked at how this ability develops in infants and to our knowledge, no study has explored the mechanisms involved in the development of this ability. Reaching to targets on the body efficiently requires a set of perceptual and motor skills that allow us to perceive and use our body parts in an organised and differentiated manner. Before planning and executing a reach, the target stimulus must be localized. First, its location on the skin has to be coded and then this information must be integrated with information about the position of the target (as well as the reaching) limb. This integration between two reference frames, one skin-based the other external, is known as tactile remapping (Heed, Buchholz, Engel, & Röder, 2015). Although recent studies have described the development of infants' ability to localize targets on the body (Lisa K. Chinn, Noonan, Hoffmann, & Lockman, 2019; Lisa K. Chinn et al., 2019; Leed, Chinn, & Lockman, 2019; Somogyi et al., 2018), the mechanisms underlying this development are not well understood.

In the present research, we will examine the hypothesis that externally provoked tactile stimulation plays an important role in the emergence of infants' ability to reach towards stimulation on their own body. Before presenting our study, we first review previous research that have described the development of reaching to the body in foetuses and infants as well as the mechanisms that have been suggested as underlying this development.

1.1. Development of reaching to the body

Foetuses frequently bring their hand to their mouth and anticipate hand-to-mouth contact by opening their mouth beforehand (Myowa-Yamakoshi & Takeshita, 2006). The kinematic pattern of these movements is distinguishable from that of movements directed towards the eye, suggesting that foetuses plan these actions based on their sensory consequences (Zoia et al., 2007). By birth, infants can accurately bring their hands toward their mouth (Lew & Butterworth, 1997; Rochat, 1993).

After birth, infants spend much of their early moments touching their own body. The two studies that have examined the development of self-touch during the first weeks show that infants follow a cephalocaudal progression with more touches to the head and torso at first, followed by more touches to the legs by 12 weeks of age (DiMercurio, Connell, Clark, & Corbetta, 2018; Thomas, Karl, & Whishaw, 2014). Analyses of hand postures during self-touch (Thomas et al., 2014) show that initially, contact with the body is incidental with fingers in a closed configuration. From about 12 weeks, movements also include palmar contacts, giving a goal-directed, exploratory quality to self-touch.

A series of recent studies have described the development of infants' ability to localize tactile stimulation on the body (Somogyi et al., 2018) or the face (Chinn, Noonan, Hoffmann, & Lockman, 2019), by attaching a small vibrating pancake motor (or buzzer) on infants' body to test reaching localization. Infants start to reach to the buzzer around five months of age, whereas younger infants respond to the stimulation in an undifferentiated way, by increasing movements of the whole body (Somogyi et al., 2018). It is by 7-8 months that infants become able to perform precise movements to act upon the stimulus and the ability to contact targets on the body and the face continues to develop during the first and second years of life (Lisa K. Chinn et al., 2019).

The studies reviewed above show that although reaching to the body is already present in foetuses and self-touch continues after birth, the more targeted ability that enables infants to act on stimulation on the body emerges much later, around 5 months and develops gradually during the first year. This is intriguing, considering that infants start to reach towards objects in external space already at 4 months (Fagard, 1998). The relative delay of targeted reaching towards stimulation on one's own body suggests that reaching towards the body and reaching towards objects in external space rely on different processes (DiMercurio, Connell, Clark, & Corbetta, 2018). What are the specific mechanisms that underlie the development of reaching to the body?

1.2. Mechanisms underlying the development of reaching to the body

One mechanism proposed in literature is the specific tactile information that self-touch provides. Touching the body entails two areas receiving tactile stimulation simultaneously (double touch) rather than just one, as in the case of stimulation arriving from the infant's' environment (single touch). Evidence shows that newborns discriminate between the two and display different patterns of rooting responses following self-touch compared to external tactile stimulation of the cheeks (Rochat & Hespos, 2002).

As self-touch is coupled with the engagement of the infant's own motor apparatus, it provides not only specific tactile information, but also contingent tactile-proprioceptive experiences (Bushnell & Boudreau, 1993). Infants detect intersensory contingency involving the body from birth, as newborns detect visual-tactile mismatch related to the face (Filippetti, Orioli, Johnson, & Farroni, 2015). A little later, from 5 months, infants detect proprioceptive-visual contingency between their own leg movements and accompanying visual cues (Bahrick and Watson, 1985). Intersensory contingency detection is thus a second mechanism that possibly underlies the development of the ability to reach to the body. This is supported by the fact that from 6 months, start to use visual reference frames when localizing stimulation on the body (Begum Ali, Spence, & Bremner, 2015; Somogyi et al., 2018) and their ability to integrate tactile-proprioceptive and visual information when reaching to the body continues to develop throughout the second year (L. K. Chinn, Hoffmann, Leed, & Lockman, 2019). Based on the research reviewed above, we can hypothesise that self-touch (whether spontaneous or provoked by external stimulation), through the specific tactile (double touch) and intersensory experience it generates, is a key mechanism underlying the development ofinfants' ability to localize tactile stimuli on the body. Still, no studies to date have directly tested this hypothesis.

1.3. The current study

We propose that externally provoked tactile stimulation gives the opportunity for infants to explore the intersensory correlations emerging from this stimulation and to act on the stimulus. For instance, when stimulated, say on the abdomen, infants can learn how to modulate such stimulation by a certain motor command, namely moving one hand to that location, integrating tactile and proprioceptive information. From about 6 months infants will also start to search for the stimulation visually, integrating tactile proprioceptive and visual information. We hypothesised that the more opportunities infants have to explore these intersensory correlations, the earlier they will be able to localize and reach to reach to discrete tactile stimuli on the body.

To test our hypothesis, we followed the development of reaching to the body in a group of 21 infants over a period from 4 to 8 months of age. We provided weekly tactile stimulation sessions to one group of infants, in their own homes, in a naturalistic setting (Buzzer stimulation condition). During these sessions, the experimenter placed a vibrating buzzer, one location at a time, on eight different locations on the infant's body. Infants in the Control group were also visited weekly in their homes by the experimenter, receiving the same amount and type of social stimulation, but no vibrotactile stimulation was provided to them (Control condition). We tested infants' ability to localize the buzzer on the eight body areas every fourth week, at 5, 6, 7 and 8 months to explore the effect of time (Test month). We coded the number of locations where infants successfully contacted the buzzer directly with the hands or fingers (Buzzer test score) as well as the reaction times for each successful contact (RT).

We expected that infants in the Buzzer stimulation condition would produce specific, localized responses to vibrotactile stimulation at earlier ages and would respond faster than infants in the Control condition. Specifically, we expected infants in the Buzzer stimulation condition to reach higher scores in the Buzzer test and to respond with shorter RTs. Regarding the progression of infants' performance with age, based on previous research (Somogyi et al., 2018), we expected that by 8 months, infants in both groups would successfully localize the buzzer and that any differences in performance between the two groups would be observed at earlier ages, when the ability to reach to targets on the body is not yet fully established.

1. Method

1.1. Participants

Twenty-one full-term infants were followed from the age of 4 months (11 girls and 10 boys, age range = 119 - 130 days, mean = 124 days) over 16 weeks. Infants were recruited from a list of local families who had expressed interest in participating in studies in infant development. Families were middle to upper class. Parents gave their informed consent before participating in the study. Infants were assigned to the Buzzer Stimulation or the Control Condition as they became available until a count of at least 10 infants per condition was reached. The experimental protocol was approved by the University ethics committee. An additional 9 infants were recruited but had to be excluded due to premature birth (n=6), visual impairment (n=1) or unavailability for full length of study (n=2).

1.2. Materials and procedure

All the infants took part in sixteen sessions, held in their homes once a week over a period of 16 weeks (as the date of the visit sometimes had to be adjusted to fit a family's schedule, +/- 4 days were allowed). The Buzzer stimulation group, but not the Control group, received tactile stimulation at each session. Tactile stimulation was provided by a vibrating buzzer that we attached to eight areas of the infant's body, one area at a time, with double-sided tape. The buzzer (1 cm Ø) was custom-made and consisted of a button battery attached to a pancake motor, with a rotation speed of 70 Hz, comparable to that found in baby teethers. All infants' ability to localize the buzzer on their body was tested at 5, 6, 7 and 8 months. Depending on usual caregiver practice, the infants were either seated supine in an infant seat during the whole session or placed supine on a flat surface. All the sessions were recorded on video. The procedure for each of the two groups was as follows.

1.2.1. Buzzer stimulation group

During each stimulation session, the vibrating buzzer was attached to eight body areas, one location at a time, for 35s; back of left hand (LH), back of right hand (RH), left belly (LB), right belly (RB), left knee (LK), right knee (RK), top of left foot (LF), top of right foot (RF), for a total of eight trials. The order of locations and side (left or right first) was randomized. While placing the buzzer on the child, the experimenter also approached her hand towards the same location on the side not receiving the target with a second buzzer, which she did not attach to the body. This way the visual cues were approximately identical for the two sides. Each trial lasted until 35s elapsed, at which point the experimenter removed the buzzer and attached it to the next location. If the infant removed the buzzer within 35s, then the experimenter replaced it to ensure that each body area was stimulated for the same amount of time for all the infants. The set of locations stimulated are shown in Fig.1.

Please insert Fig.1 about here.

1.2.2. Control group

To control for the effect of the social stimulation provided by the experimenter's weekly visit of infants in the Buzzer stimulation group, she also visited infants in the Control group, at the same intervals. She proceeded in the same manner as in the Buzzer stimulation group, approaching the infant's body, one location after the other, with the two buzzers in hand, only in this group, she did not actually attach the buzzer.

1.2.3. Testing infants' ability to localize stimulation on their body: Buzzer test

We tested the ability of infants in both the Buzzer stimulation and the Control group to localize the buzzer every fourth week with the Buzzer test, at 5, 6, 7 and 8 months. The Buzzer test procedure was identical to that of the buzzer stimulation sessions, only this time the buzzers were not placed back on the infant's body if the infant removed the buzzer before the 35s elapsed. The vibrating buzzer was attached to the same eight body areas, one location at a time, in randomized order.

For each trial, we coded whether the infant contacted the buzzer with the hand or fingers, grasping it or performing a pinch movement to retrieve it. Infants scored 1 if any contact was produced during the trial and 0 if the behaviour was absent (Buzzer contact: contact or no contact during trial). Note that we did not code how many times infants contacted the buzzer, only whether contact occurred or not. If the infant contacted the buzzer, we coded the location (Buzzer location: LH, RH, LB, RB, LK, RK, LF or RF) as well as the reaction time or number of seconds elapsed between buzzer placement and contact (RT). We then calculated the total number of locations (out of eight) where infants successfully contacted the buzzer which yielded a score for each test session (Buzzer test score: maximum 8).
Using the video recordings, we also coded infants' looking behaviour, but because of the difficulty of extracting eye position from the videos, and also because looking and touching sequences were often intermingled in a complex way, it was not possible to determine precisely whether look and touch were precisely coordinated. We therefore simply recorded whether or not in a given trial there was a look at the buzzer (Buzzer look).
Buzzer test score, Buzzer contact, RT and Buzzer look were used as dependent variables for subsequent analyses.

2. Results

2.1. Preliminary analyses

Infants' behaviour was coded from the videos and 7 infants' (30%) behaviour was coded independently by a second observer to assess inter-observer reliability. Reliability between the two observers was satisfactory for all coded variables (mean Cohen's $\kappa = 0.88$, range = 0.76–1.00). Preliminary analyses found no significant effect of sex ($p = .09$) or order of locations ($p = .08$) on Buzzer contact, so these variables were excluded from further analyses.

2.2. Effect of weekly buzzer stimulation on manual localization of buzzer

The GEE analyses (N=21) to investigate the effect of Stimulation (between subjects variable: Buzzer stimulation vs Control condition) and Test month (within subjects covariable: 5mo, 6mo, 7mo and 8mo) on the number of locations (out of eight) where infants successfully contacted the buzzer (dependent scale variable: Buzzer test score, maximum 8) revealed a significant main effect of both variables (Stimulation: Wald$\chi 2 = 4.5$, df = 1, $p = .03$; Test month: Wald$\chi 2 = 248$, df = 3, $p < .001$). We found no interaction between the two, indicating that the effect of buzzer stimulation was independent of age. Subsequent pairwise comparisons yielded the following results.

Regarding the effect of Stimulation, Buzzer test scores (5mo, 6mo, 7mo and 8mo scores collapsed) were significantly higher in the Buzzer stimulation group ($M_{Stimulation} = 4.01$) than in the Control group ($M_{Control} = 5.02$, $\chi^2(1, N = 84) = 4.5$, $p = 0.03$). This indicates that infants who received weekly buzzer stimulation between 4 and 8 months were significantly better than controls in localizing buzzers on their body.

Regarding the effect of Test month, Buzzer test scores increased significantly in both groups with each month, until 7 months in the Stimulation group and until 8 months in the Control group (Control group: $M_{Control5mo} = 1$; $M_{Control6mo} = 3.3$, $p = .01$; $M_{Control7mo} = 4.6$, $p = .001$; $M_{Control8mo} = 7.2$, $p = .01$; Buzzer stimulation group: $M_{Stimulation5mo} = 1.6$; $M_{Stimulation6mo} = 4.3$, $p < .001$; $M_{Stimulation7mo} = 6.9$, $p < .001$; $M_{Stimulation8mo} = 7.4$, n.s.). Infants in the Stimulation group localized the buzzer in 7 of the 8 trials already at 7 months ($M_{Stimulation7mo} = 6.9$) which explains why their Buzzer test score did not increase significantly after this age.

Comparisons of the two groups at each Test month showed that at 7 months, (but not at 5mo, 6mo or 8mo), infants in the Buzzer stimulation group scored significantly higher on the Buzzer test ($M_{Stimulation7mo} = 6.9$) than infants in the Control group ($M_{Control7mo} = 4.4$, $p = .01$).

In sum, the above results show that overall, infants who received weekly buzzer stimulation between 4 and 8 months were significantly better than controls in manually localizing buzzers on their body. Infants in both groups developed significantly from one month to the other, however, weekly buzzer stimulation facilitated this development. The overall difference in performance between the two groups was driven by differences at 7 months, showing that weekly stimulation with the buzzer starting from 4 months resulted in significant differences three months later, at 7 months. By 8 months, infants in the Control group ‘caught up’ with infants in the Buzzer stimulation group and at this age, all the infants could localize the buzzers on most, if not all, of the body areas stimulated. Mean Buzzer test scores for each condition and Test month are shown in Fig. 2.

Please insert Fig. 2 about here.

2.3. Differences across body locations

The GEE analysis (N = 21) to explore the effect of Buzzer location (LH, RH, LB, RB, LK, RK, LF or RF), Stimulation (between subjects variable: Buzzer stimulation vs Control condition) and Test month (within subjects covariable: 5mo, 6mo, 7mo and 8mo) on successful Buzzer contact (contact or no contact during trial) revealed a significant main effect of all three variables (Buzzer location: Waldχ^2 = 34, df = 7, p < .001; Stimulation: Waldχ^2 = 194, df = 1, p < .001; Test month: Waldχ^2 = 1198, df = 3, p < .001). We found no interaction among the three, indicating that the progress with age of infants' ability to contact the buzzer followed a similar trend in the two groups. We compared Buzzer Contact frequency for left (LH, LB, LK, LF) and right (RH, RB, RK, RF) locations and did not find any laterality effects, therefore for subsequent pairwise comparisons we collapsed data from the two sides, which yielded data for four body areas: Hands, Belly, Knees and Feet. We conducted pairwise comparisons to investigate whether certain areas were easier than others to localize and also to compare how infants progressed in their ability to contact the buzzer in the four body areas.

To see which areas were the easiest for infants to localize, we compared frequency of Buzzer contact across the four body areas, both groups and all ages collapsed. Buzzer contact was most frequent when the buzzer was on the Knees (Waldχ^2 = 12.16, df = 3, p < .001, compared to Hands: p < .001; Belly: p = .008; Feet: p < .001). The Belly was the second easiest location (Waldχ^2 = 12.16, df = 3, p < .001, compared to Hands: p < .035; Knees: p = .008; Feet: p = n.s). There were no differences in frequency of Buzzer contact between the Hands and the Feet.

Next, we compared how infants progressed in the two groups in their ability to contact the buzzer in the four body areas from one month to the other. For the Hands, infants in the Buzzer stimulation group, but not controls, developed significantly in their ability to contact the buzzer between 5mo and 6mo (χ^2 = 6.18, p = .008). Infants in the Control group developed significantly between 7mo and 8mo (χ^2 = 9.86, p = .002), but not earlier. For the Belly, there were no significant differences from 5mo to 6mo in either group, but both groups developed significantly between 5mo and 7mo (Buzzer Stimulation group: χ^2 = 10.76, p = .001; Control group: χ^2 = 11.1, p = .001). For the Knees, infants in the Buzzer Stimulation group developed significantly between 6mo and 7mo (χ^2 = 5.03, p = .05; χ^2 = 8.14, p < .01) whereas infants in the Control group developed significantly between 5mo and 6mo and continued to develop between 7mo and 8mo (χ^2 = 5.14, p = .004; χ^2 = 8.14, p < .01). For the Feet, infants in the Buzzer Stimulation group developed significantly between 6mo and 7mo (χ^2 = 9.73, p = .002), whereas infants in the Control group developed significantly between 7mo and 8mo (χ^2 = 4.14, p = .01).

All in all, the above results show that the manual localization of the buzzer was easiest when the buzzer was on the knees and the belly. Localization was more difficult when the buzzer was on the hands or the feet, which is possibly why it is in these two areas that buzzer stimulation facilitated infants' development the most. The earliest effect of buzzer stimulation appeared between 5 and 6 months, when infants in the Buzzer Stimulation group performed significantly better than controls in localizing the buzzer on the hands. Similarly for the feet, infants in the Buzzer Stimulation group, but not controls, developed significantly between 6 and 7 months.

Lisa and Jeff, can you perhaps help out with calculating the probability of success for each location?

2.4. Effect of weekly buzzer stimulation on visual localization of buzzer

The GEE analysis (N = 21) for the effect of Stimulation (Buzzer stimulation vs Control condition) and Test month (5mo, 6mo, 7mo and 8mo) on Buzzer look (look or no look) revealed a significant main effect of both variables (Stimulation: Wald$\chi^2 = 3$, df = 1, p = .05; Test month: Wald$\chi^2 = 32.3$, df = 3, p < .001). No interactions were found between the two variables. Subsequent pairwise comparisons yielded the following results.

Buzzer look was significantly more frequent in the Buzzer stimulation group (38% of trials) than in the Control group (24% of trials, $\chi^2 = 6.8$, p = 0.01). This indicates that weekly buzzer stimulation facilitated visual localization of the buzzer.

Frequency of Buzzer look increased significantly from one month to the other (5mo to 6mo: p = .002; 6mo to 7mo: p = .001 and 7mo to 8mo: p < .001). By 8 months, infants looked at the buzzer on most trials (83%), at 7 months they still looked on only about third of the trials (27%), showing that at 7 months visual search was not a dominant strategy in localizing the stimulation.

Mean Buzzer look frequencies for each condition and Test month are shown in Fig. 4.

Please insert Fig. 4 about here.

1.1. Reaction times

As only 16% of infants were able to localize the buzzer at 5 months, we only compared reaction times at 6, 7 and 8 months. The GEE analyses (N=21) to investigate the effect of Stimulation (between subjects variable: Buzzer stimulation vs Control condition) and Test month (within subjects covariable: 6mo, 7mo and 8mo) on infants' reaction times when they successfully contacted the buzzer (dependent scale variable: RT in seconds) revealed a significant main effect of both variables (Stimulation: Wald$\chi 2 = 4.2$, df = 1, p = .04; Test month: Wald$\chi 2 = 25.1$, df = 2, p < .001).

Discussion

In this longitudinal study, we explored the effect of tactile stimulation on the development of 4- to 7-month-old infants' own body know-how, more specifically, their ability to reach for vibrotactile targets on their own body. We hypothesised that infants who receive weekly (non-social) tactile stimulation on their body between 4 and 7 months would produce specific, localized responses to vibrotactile stimulation provided by buzzers at earlier ages and would respond faster than controls. Our hypothesis was confirmed, as by 7 months, infants who received weekly tactile stimulation localized the buzzer on significantly more body areas, contacted the buzzer and also looked at it more frequently than controls.

Thus, tactile stimulation facilitated the emergence of own body know-how and infants' ability to reach for buzzers on their body. What may be the mechanism that conveys this effect? We propose that externally provoked tactile stimulation gives the opportunity for infants to explore the sensory correlations emerging from this stimulation and to act on the persisting stimulus. When stimulated on their body, infants can learn how to modulate such stimulation by a certain motor command, namely moving one hand to that location. This then provides a mechanism by which the infant will eventually be able to reach towards a buzzer that is attached to that location.

Points for discussion.

Why does targeted reaching towards the body emerge later than reaching towards objects outside the body?

Delay of reaching towards targets on own body: Interestingly, infants engage in self-touch and appear to make grasping motions towards their own body at a younger age (Corbetta et al., 2014; Marshall and Meltzoff, 2015; Thomas et al., 2015) than the age at which infants in the present study as well as Somogyi et al.'s study (2018) grasped discrete vibrotactile targets on the hands and the legs. Why is there a delay in making movements towards own body? One explanation is that spontaneous self-touch is not necessarily directed toward a specific location of the body, therefore the demands of planning and executing a reach are less than when reaching to a discrete target on the body. Corbetta et al. (2019) directly tested self-touch, reaching to body targets, and reaching to external objects in the same infants to study whether they use different motor strategies during these different types of reaching.

We have seen that 5- and 6-month-old infants relied on vision to localize targets only about 30% of trials, executing eventual reaches on the basis of tactile and associated proprioceptive information. At 7 months, frequency of looks increased significantly to 70% of trials. This observation confirms earlier research showing that infants also start to use visual reference frames to localize a tactile stimulus placed on the skin around 6 months of age (Heed et al., 2015; Begum Ali et al., 2015). Neural responses associated with limb mapping in external space continue to develop between 6 and 10 months (Rigato et al., 2014).

The development of own body know-how also has an important role in developing a sense of a separate self. Pioneers in developmental psychology like Piaget (1936/52) or Wallon (1941) theorised that new-borns live in a fusion of the self and the environment, unable to distinguish between external and internal stimuli. They suggested that infants develop the concept of a separate self through countless informal experiments during the first six months of life, gradually realising that the external world is not an extension of themselves.

The demands of planning and executing a reach are possibly less when infants spontaneously engage in self-touch than when they reach to a well-defined target on the body, which can explain why the latter emerges later. This relatively late emergence of the ability to reach for targets on the body indicates this skill may develop independently from the ability to reach for objects in external space or of the that iWhy is there a delay in making movements towards own body? Corbetta et al. (2019) directly tested self-touch, reaching to body targets, and reaching to external objects in the same infants to study whether they use different motor strategies during these different types of reaching.
already engage in self-touch and make grasping motions towards their own body from the first weeks (Corbetta et al., 2014; Marshall and Meltzoff, 2015; Thomas et al., 2015) and

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Figures

Figure 1a Set of locations stimulated on infants in the Buzzer stimulation group. During each stimulation session, the vibrating buzzer (embedded picture) was attached to eight body areas, one location at a time, for 35s; back of left hand, back of right hand, left belly, right belly, left knee, right knee, top of left foot, top of right foot, for a total of eight trials. The order of locations was randomized.

1b A 6-month-old infant collecting a small "buzzer" (a vibrotactile target, indicated by the yellow arrow) from her right foot during test.

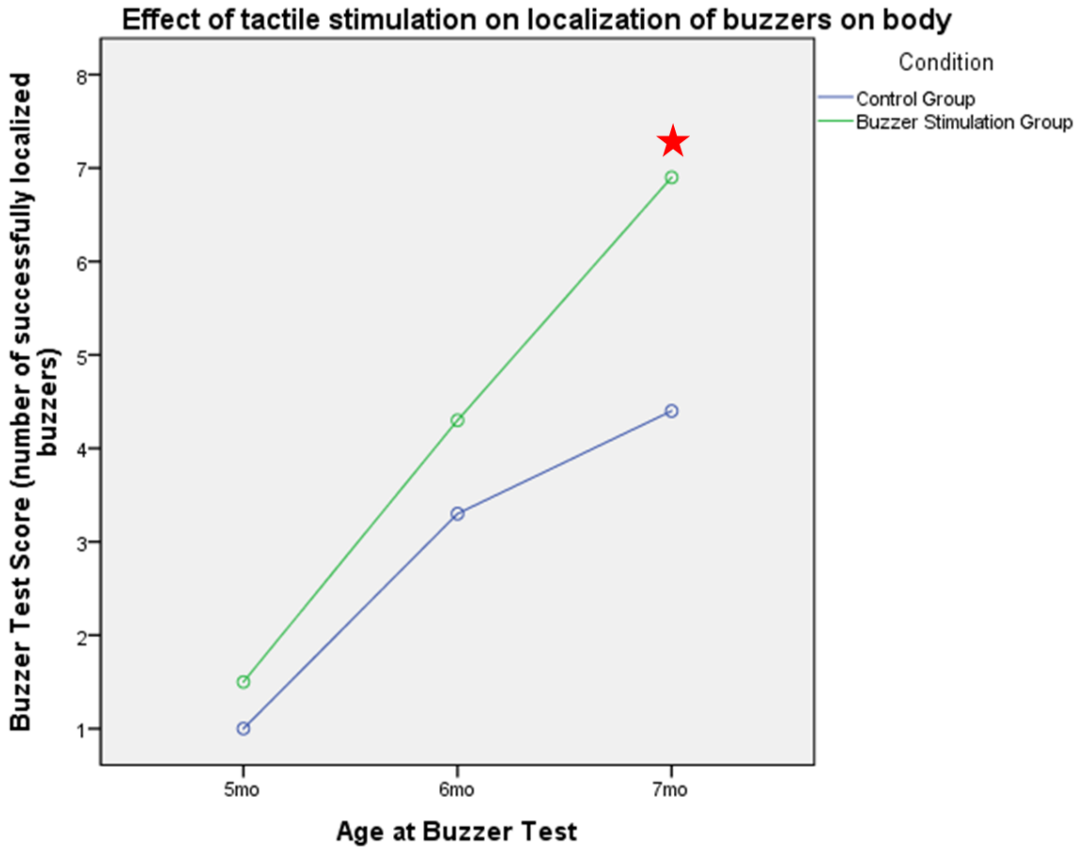

Figure 2 Number of successfully localized buzzers on body as a function of tactile stimulation and age.

Figure 3 Percentage of trials where buzzer was contacted with the hand or fingers, as a function of tactile stimulation and age.