# Effects of posture on tactile localisation by 4 years of age are modulated by sight of the hands: Evidence for an early acquired external spatial frame of reference for touch

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# ABSTRACT

Adults show a deficit in their ability to localize tactile stimuli to their hands when their arms are in the less familiar, crossed posture. It is thought that this “crossed-hands deficit” arises due to a conflict between the anatomical and external spatial frames of reference within which touches can be encoded. The ability to localize a single tactile stimulus applied to one of the two hands across uncrossed-hands and crossed-hands postures was investigated in typically developing children (aged 4 to 6 years). The effect of posture was also compared across conditions in which children did, or did not have, visual information about current hand posture. All children, including the 4-year-olds, demonstrated the crossed hands deficit when they did not have sight of hand posture, suggesting that touch is located in an external reference frame by this age. In this youngest age-group, when visual information about current hand posture was available, tactile localization performance was impaired specifically when the children’s hands were uncrossed. We propose that this may be due to an early difficulty with integrating visual representations of the hand within the body schema.

# Use of an external frame of reference for touch by 4 years of age is modulated by sight of the hands

The literature on the development of spatial frames of reference in early life, which has spanned more than three decades, has focused on the emergence of ability to locate *visual* stimuli and targets with respect to environmental (allocentric, and object-centred) spatial coordinates. There remains considerably wide variation in opinion concerning how and when infants and children become able to make use of such environmental frames of reference. Some researchers have promoted the view that an ability to orient oneself in the external visual world develops gradually in infancy (Acredolo, 1978; J. G. Bremner, 1978; J. G. Bremner, Hatton, Foster, & Mason, 2011), and childhood (Nardini, Thomas, Knowland, Braddick, & Atkinson, 2009), and as a consequence of the sensorimotor experiences of moving within it (e.g., Piaget & Inhelder, 1967). Others have argued for an inherited, or at least early-acquired provision of an ability to code visual space in external coordinates (e.g., A. J. Bremner, Bryant, Mareschal, & Volein, 2007; Hermer & Spelke, 1994; Kaufman & Needham, 2011; Lee & Spelke, 2010).

However, everyday spatial behaviour involves locating *multisensory* stimuli in the environment, and relative to ourselves, with such stimuli arriving mostly through vision, hearing, and touch in various uni-, bi- or tri-modal combinations (see Holmes & Spence, 2004). And yet, only one study that we know of (Bremner, Mareschal, Lloyd-Fox, & Spence, 2008; see below) has investigated how we develop an ability to *reorient* to targets which contain no relevant visual information. This is a striking omission given that a wide range of human and primate spatial behaviours involve locating stimuli arriving though multiple sensory channels (Graziano, Gross, Taylor & Moore, 2004; Holmes & Spence, 2004). In this paper we report findings from a study investigating the development in early childhood of an ability to represent tactile stimuli with respect to an external spatial frame of reference, and to relocate such tactile locations in external space across changes in the posture of the body. To represent the location of a touch in the environment we make use of a variety of different sources of sensory information, including vision, proprioception, and even the sounds which are associated with tactile events and the body. This multisensory aspect of touch localization makes it a particularly interesting skill to study in childhood, given that recent research has demonstrated significant developments in the processes involved in weighting and integrating the senses across early to late childhood (e.g., see Bremner, Lewkowicz & Spence, 2012; Gori, Del Viva, Sandini & Burr, 2008; Nardini, Jones, Bedford & Braddick, 2008; Nava & Pavani, 2013).

The task of locating a touch in external space is by no means a simple spatial task. Touch is initially coded with respect to coordinates on the somatosensory sheet, and yet the location of the object or event which gives rise to a tactile stimulus can change with respect to location on the skin as the body moves around the environment, or indeed as the limbs move with respect to the body. In order to represent the location of a touch in external coordinates adults, and indeed adult monkeys, dynamically remap the relation between tactile stimuli and external coordinates (Azañón & Soto-Faraco, 2008; Kitazawa, 2002; Overvliet, Azañón & Soto-Faraco, 2011; Graziano et al., 2004).

The process of mapping tactile stimuli from a location on the body to external coordinates can be observed in the “crossed hands deficit” which has typically been exhibited by adults in the context of tactile temporal order judgement (TOJ) tasks. When tactile stimuli are presented across the hands or feet at short stimulus onset asynchronies, adults make more errors in identifying which of their two hands was touched first when their limbs are crossed contralateral to their usual sides of the midline (Schicke & Röder, 2006; Shore, Spry, & Spence, 2002; Yamamoto & Kitazawa, 2001). This crossed-hands deficit has been interpreted as being due to conflict between the location of the touch in its usual location with respect to the body (what we will refer to as its anatomical location) and its location in external space. Outside of TOJ tasks, researchers have also observed that the early stages of saccades to tactile stimuli on the hand are occasionally made towards the wrong hand when the hands are crossed (Overvliet, Azañón & Soto-Faraco, 2011; Groh & Sparks, 1996).

Two developmental studies have used the crossed-hands manipulation to investigate the development of an ability to locate tactile stimuli in an external frame of reference in early childhood (Pagel, Heed & Röder, 2009), and infancy (Bremner, Mareschal, Lloyd-Fox & Spence, 2008b). These studies have yielded somewhat conflicting pictures of tactile spatial development. Whereas Bremner et al. (2008b) showed that infants demonstrate a crossed hands deficit in manual orienting to single tactile stimuli at 6.5 months but not at 10 months of age, Pagel et al. (2009) did not observe a crossed hands deficit in their TOJ task until 5.5 years. Correspondingly, Pagel et al., and Bremner et al. offer different accounts of the emergence of an external frame of reference for touch; Bremner et al. argue that this is available early in life, whereas Pagel et al., argue that it appears in early childhood as a result of visual experience. One focus of the current investigation is to attempt to resolve these conflicting claims and to understand why this inconsistent pattern of findings has arisen.

Our processing of tactile stimuli is influenced by information about the body which is available from other modalities. Visual information has been shown to modulate tactile perception and localization in adults. Studies of the rubber hand illusion have demonstrated that vision of a fake hand being stroked can capture tactile sensations to the visual location of the stroke (Botvinick & Cohen, 1998; Pavani, Spence & Driver, 2000). Additionally, viewing a hand receiving a tactile stimulus modulates processing in the somatosensory cortex (Longo, Pernigo & Haggard, 2011; Taylor-Clark, Kennett & Haggard, 2002; Cardini, Longo & Haggard, 2011), improves tactile acuity (Longo, Cardozo & Haggard, 2008; Press, Taylor-Clark, Kennett & Haggard, 2004), and can even reduce the intensity of acute pain (Longo, Iannetti, Mancini, Driver & Haggard, 2012).

The studies described above show that vision of the body can modulate tactile perception. Vision of a stimulated limb can also inform individuals about limb posture and location (Graziano, 1999), and change the ways in which limb position is represented in the brain (Lloyd, Shore, Spence & Calvert, 2003; Rigato, Bremner, Mason, Davis & van Velzen, 2013). Studies with children have shown that there are substantial improvements in the use of vision to reach in early childhood (Ferrell-Chapus, Hay, Olivier, Bard and Fleury, 2002; Renshaw, 1930). Recent studies have also shown that the sensory weightings which children use to locate their limbs undergo a number of noticeable developmental changes in early childhood. Bremner, Hill, Pratt, Rigato & Spence (2013) have shown marked increases in the influence of visual cues on perceived hand location between 4 and 6 years. Investigating the development of children's responses to the rubber hand illusion, Cowie, Makin, & Bremner (2013) have demonstrated a particularly strong influence of a visual illusory hand on the perceived location of the real hand from 6 to 9 years of age which becomes more moderate into adulthood.

Thus, in addition to attempting to clarify the, at present, conflicting literature on the development of tactile spatial representation we also sought to investigate the influence of visual cues to the body on children's developing tactile spatial abilities. We developed a new task for assessing tactile localization in young children, which required children to locate a single tactile stimulus presented to one of their hands on each trial. We examined children's localization of touches in external space by comparing performance on tactile localization across crossed- and uncrossed-hands postures. Localisation of touch in external coordinates is indexed by poorer performance in the crossed- relative to the uncrossed-hands condition, due to conflict between current and usual locations of the tactile stimulus in external spatial coordinates. Given the more noisy and less accurate judgements which children generally display on perceptual discrimination tasks, we reasoned that the most suitable context in which to study the crossed-hands deficit in children may be a task which requires a judgment about the location of a single tactile stimulus (rather than 2 stimuli as in the tactile TOJ tasks discussed above). Additionally, presenting a single tactile stimulus allows a more straightforward comparison with studies of tactile localization in infants (Bremner et al., 2008b), as such studies also only used single stimuli.

Given recent observations of changes in the visual weighting of hand position across childhood (e.g., Bremner et al., 2013; Cowie et al., 2013) we decided to investigate whether the presence of visual cues to hand position (in addition to proprioceptive cues) varied in their effect on tactile spatial localization across early childhood. To do this we compared children's tactile localization accuracy across postures either with or without sight of their hands. We expected that children would perform better with their hands in the uncrossed posture, compared to the crossed posture.

# Methods

## Participants

91 participants aged 4 to 6 years (51 male) took part in the study. 14 participants were excluded prior to analyses, as they either did not respond correctly on five consecutive trials in the practice session (4-year-olds: n = 7; 5-year-olds: n = 3; 6-year-olds: n = 3), or did not appear to understand task instructions (4-year-olds: n = 1) leaving 77 participants (see Table 1 for further characteristics of the included participants).

--Insert Table 1 about here--

## Apparatus and Materials

Two voice coils (30x40mm) driven with a 220Hz sine wave and controlled by custom software scripted in E-Prime acted as vibrotactile stimulators (tactors). These two tactors were fixed to a board 30cm apart. A ledge covered this board, on which were placed a stuffed toy hedgehog and penguin (both 13x10cm), the hedgehog over the right tactor, and the penguin over the left tactor. A detachable cover (35x40cm) was attachable to the front edge enabling the experimenter to conceal participants' arms and hands and, by extension, their arm posture (Figure 1). The experiment was conducted in the participant's classroom. The tactors emitted a noise of 49.7 dBA, whilst the average ambient noise in the classroom was 65.5 dBA. We conducted a short study on a subset of participants aged between 5 and 6 years (mean age = 5.8 years, SD = .66) in which they were asked to locate the stimulated tactor using only auditory cues. The participants were seated with the equipment set up in front of them and their hands in their laps. The experimenter triggered a trial and asked: "Which animal made a sound: the penguin or the hedgehog?" If a participant was unable to provide an answer, the experimenter prompted them to guess. Participants completed 12 trials, with a mean auditory localisation accuracy of 54.12% (SD = 13.35%). A one sample t test showed that the participants were performing at chance, $\underline{t}(7) = .87$, n.s., $\underline{d}=.66$.

--Insert Figure 1 about here--

## Procedure

In a short practice phase, the experimenter (JBA) placed the participant's index fingers on the tactors, whilst the participant adopted an uncrossed-hands posture with their hands visible. Each vibrotactile stimulus was presented for 200ms. The practice phase consisted of 6 trials. On each practice trial only one of the participant's hands was stimulated. Across the 6 practice trials, each hand was stimulated three times, in a randomized order. Following each of these practice stimuli, the researcher asked the participant: "Who tickled your fingers: the penguin or the hedgehog?" In order to proceed to the experimental phase, participants were required to correctly locate the stimulus on 5 consecutive trials. If participants were unable to meet this criterion, they did not continue with the study.

The experimental trials were identical to the practice trials except that the experimenter (JBA) was blind to the accuracy of the child's answer during the experimental trials. Participants' verbal responses were recorded by the experimenter on a computer. In the experimental phase, there were four separate blocks of trials: (i) Uncrossed-hands, Visible (ii) Uncrossed-hands, Covered (iii) Crossed-hands, Visible (iv) Crossed-hands, Covered. Between blocks, the experimenter always moved the child's hands into a different posture and/or covered or uncovered their arms. Each block consisted of 20 trials (10 vibrotactile stimulations to each hand), across which the order of left and right stimuli was randomized. Thus, across the whole experimental session (4 blocks) there were 80 trials. The order of the blocks was fully counterbalanced across participants, yielding 24 separate order conditions[1].

## Results

We derived a measure of the children's tactile localisation accuracy by calculating the percentage of trials on which they made a correct response in each condition. One-sample t-tests of this percentage accuracy score showed that all three age groups were performing reliably above chance (50%) in all conditions (Table 2).

--Insert Table 2 about here--

Figure 2 shows children's percentage accuracy across both the posture conditions and the two hand conditions (in which their hands were either visible or not). We used a mixed measures 2 x 2 x 3 ANOVA to investigate the effects of the within-subjects factors of Posture (Uncrossed-hands / Crossed-hands), and View (Covered / Visible), and the between-subjects factor of Age (4-year-olds / 5-year-olds / 6-year-olds) on children's percentage accuracy scores. This revealed a main effect of Age, F(2, 74) = 12.00, p < .001, $\eta_p^2$ = .25, showing that, across conditions, the older children were more accurate when localizing tactile stimuli. Tukey's HSD tests showed that this effect was drive by poorer performance in the 4-year-olds (*M =80.3%*, *SD =14.55%*) than both the 5-year-olds (*M* = 89.29%, *SD* = *6.8%*) (p = .004) and the 6-year-olds (*M* = 92.78%, *SD* = 4.96%) (p < .001). There was no reliable difference in performance between the 5- and the 6-year-olds. A main effect of Posture was also observed, F(1, 74) = 13.61, p = .001, $\eta_p^2$ = .16, indicating that the children were reliably better at localizing touches in the uncrossed hands posture than the crossed hands posture (the crossed-hands deficit), across age-groups. We also observed an interaction of Posture x View, F(1, 74) = 5.09, p = .027, $\eta_p^2$ = .06, and a marginally significant interaction of Age x Posture x View, $F(2, 74) = 2.78$, $p = .069$, $\eta_p^2=.07$.

--Insert Figure 2 about here--

We first investigated the Posture x View interaction with four post-hoc comparisons. To correct for type 1 error, the alpha value was bonferroni corrected to $p = .013$. First, we conducted two comparisons looking at the effect of posture on tactile localisation. These comparisons were one-tailed because we predicted better performance in the uncrossed-hands posture than in the crossed-hands posture. When participants did not have sight of their hands, their tactile localization was worse in the crossed-hands posture than in the uncrossed-hands posture, $t(76) = 4.33$, one-tailed $p < .001$, $d = .532$; i.e., they showed the "Crossed-hands deficit". However, this effect disappeared when participants had sight of their hands, $t(76) = 1.123$, n.s., $d = .15$. To further explore the interaction of Posture x View, we examined the effect of View within each of the posture conditions using paired sample t-tests. Thus, two further post-hoc t-tests were conducted. No differences between visible and covered conditions were found in the uncrossed posture [$t(76) = 2.03$, n.s., $d = .20$] or the crossed posture [$t(76) = 1.21$, n.s., $d = .14$].

Given that the interaction of Age x Posture x View was very close to the significance level of $p = .05$, we proceeded with post-hoc analyses. To do this we conducted three repeated measures 2 x 2 ANOVA (Posture: Uncrossed-hands / Crossed-hands x View condition: Hands covered / Hands visible), one for each age-group. In order to avoid an increase in type 1 error associated with these multiple analyses the $\alpha$ value for these ANOVAs was corrected to $p = .017$. The 6-year-olds and 5-year-olds both showed significant main effects of Posture, F(1, 29) = 6.74 p = .015, $\eta_p^2$= .19 and F(1, 25) = 13.49, p = .001, $\eta_p^2$= .36 respectively, but no other main effects or interactions. However, the 4-year-old group demonstrated a significant interaction of Posture x View, F(1, 21) = 7.14, p = .014, $\eta_p^2$= .25.

Four post-hoc paired sample t-tests were used to investigate this interaction and so the alpha value was bonferroni corrected to p = .013. First, we conducted two one-tailed comparisons looking at the effect of posture on tactile localisation. These showed that, as above, 4-year-olds' tactile localization accuracy was worse in the crossed-hands posture when they were unable to see their hands, t(21) = 2.53, one-tailed p = .009, d = .48. However, once again, this effect was not present when participants had visual information about their current hand posture, t(21) = 1.22, n.s., d = .26.

We again further explored the interaction of View and Posture, with additional post-hoc tests to examine the effect of View within each of the posture conditions. The 4-year-olds also perform worse in the uncrossed posture when their hands are visible, compared to when their hands are covered, t(21) = 2.78, two-tailed p = .011, d = .48. No difference between visible and covered conditions was found in the crossed-hands posture for this age group, t(21) = 1.51, n.s., d = .27. Figure 3 demonstrates the interaction of Posture and View on the 4-year-olds's performance, by displaying percentage accuracy with visible and covered hands on a participant-by-participant basis (plotted separately for uncrossed and crossed hands posture conditions; 4-year-olds old). This figure highlights the fact that, specifically in the uncrossed hands posture, 4-year-olds' were worse at localizing tactile stimuli when their hands were visible than when they were covered.

--Insert Figure 3 about here--

## Discussion

If we are to correctly locate an unseen touch in external space, we need to know where our limbs are positioned in the environment. In the reported study, in which we examined tactile localization in 4- to 6-year-olds, we have established that all of these age-groups, when sight of the hands is not available, exhibit a deficit in localizing single touches to the hands when the hands are in a crossed-hands posture; this deficit indicates that these participants locate touches in external spatial coordinates[2]. The fact that the youngest children whom we tested, 4-year-olds, exhibited the crossed-hands deficit demonstrates that an external frame of reference for localizing touches to the body is already in use by this age.

Evidence of the crossed-hands deficit (albeit when the hands were not visible) in the youngest age group tested in our study is consistent with demonstrations of a crossed-hands deficit in young infants' manual orienting behaviours at 6.5 months (Bremner, Holmes & Spence, 2008), and reinforces claims that an external frame of reference for coding tactile space is available, albeit perhaps in primitive form, from early in life (Bremner et al., 2008; Bremner & Cowie, 2013). Indeed, this possibility is consistent with findings from studies indicating that external spatial coding of *visual* objects and scenes may be available early in infancy (see Bremner et al., 2007; Kaufman & Needham, 1998, 2011).

Interestingly, the crossed-hands effect was modulated by sight of the hands; it was only when children did not have sight of their hands that the crossed-hands deficit was observed. Indeed, this may explain why we were able to observe the crossed hands deficit earlier than Pagel et al. (2009). In their study, the children's hands were visible throughout. But, what might account for the interaction between posture and sight of the limbs? One possibility is that the provision of visual in addition to proprioceptive information about posture ameliorated the crossed-hands deficit by enabling children to better remap tactile locations when their hands are in the less frequently adopted crossed-hands posture. However, the interaction between posture and sight of the limbs in the 4-year-olds was not driven by effects in the crossed-hands posture condition, but rather by the uncrossed-hands posture condition. Performance in the uncrossed-hands posture was enhanced when the children's hands were hidden; i.e., when only proprioceptive cues to posture were available, and so it seems unlikely that vision of the hands has its affect on performance by improving tactile remapping.

That vision of the hands modulated performance in the uncrossed-hands posture condition in 4-year-olds points to a particular role at this age for visual cues to hand position in tactile localization with regard to a spatial representation of the body in its most typical layout (i.e., with regard to a representations of the canonical layout of the body). Based on previous demonstrations of crossed-hands effects in 6.5-month-olds Bremner et al. (2008a) suggest that from infancy we have a prior expectation that a given tactile stimulus will occur in the place in external space where the relevant limb would typically rest. Under this account, the crossed hands deficit is better envisaged as an enhancement of tactile localization accuracy when the body is in a canonical posture (e.g., uncrossed hands), rather than as a deficit when in less familiar postures (e.g., crossed hands). This is consistent with Pagel et al.'s observation that development of tactile localization in early childhood proceeds via an enhancement of localization in the typical layout of the body.

But why was tactile localization performance worse when the children were provided with visual information about posture in addition to proprioception? On first inspection it seems counterintuitive that the provision of less perceptual information concerning body posture would enhance tactile spatial localization performance. However, we propose that in early childhood, due to difficulties in integrating visual cues into the body schema, under certain circumstances sight of the hands and arms may actually interfere with localization of touch.

The integration of visual cues concerning body posture into the body schema has a particularly gradual course of development across infancy and early childhood (for a review, see Bremner & Cowie, 2013). An ability to visually orient towards a tactile stimulus only emerges slowly across the first year of life (Bremner et al., 2008). Vision of the hands is similarly irrelevant to the first successful reaches which infants make; these are performed equally well with sight of the hands or in the dark (e.g., Robin*,* Berthier & Clifton, 1996). The beginnings of visually-directed reaching emerge in the second year of life at the earliest (Carrico & Berthier, 2008; although see Babinsky, Braddick & Atkinson, 2012), and developments in visual guidance of reaching continue across childhood. Reliance on visual information to localize hand position continues to increase until around 5.5 years of age (Bremner et al., 2013), and it is not until approximately 9 years of age that children are adult-like in the extent to which they use visual feedback of hand movements when accommodating for prismatic shifts in visual targets (Hay, 1979; Ferrel-Chappus, Hay, Olivier, Bar & Fleury, 2002; see also Smyth, Peacock & Katamba, 2004).

We propose that the lack of integration of visual postural cues into the body schema means that visual cues to posture actually interfere with the advantages bestowed by the canonical representation of the layout of the body (i.e. the benefit which would usually be gleaned from the body resting in its typical posture). Children of the ages tested in the reported study (4- to 6-year-olds) are in a period of sensorimotor development in which they are novices at using visual cues to locate the limbs and reach to visual targets. Visual cues to the posture of the hands may lead them into invoking a representation of current limb posture (the body schema) in preference to the heuristics provided by the canonical body representation – leading to poorer performance specifically in the uncrossed hands posture.

One further issue remains to be addressed, namely, how the patterns of tactile localization performance seen here in children relate to those observed in the first year of life. Bremner et al. (2008b) demonstrated a crossed-hands deficit in infants' manual orienting responses to vibrotactile stimuli at 6.5 months of age, but not in 10-month-olds. Given that the 6.5-month-olds demonstrated a crossed hands deficit, which is then resolved by 10 months, what might explain the subsequent reappearance of the deficit between 10 months and 4 years? The explanation which we think is most likely, is that the processes underlying crossed-hands effects observed in young children are different to those in infancy. Whereas the reduction in the crossed-hands deficit which we see between 6.5 and 10 months of age in infancy may be due to a developing ability to resolve a difficulty with locating tactile stimuli in external space (in anything other than a canonical posture of the body; see Bremner et al., 2008a), the increasing crossed-hands deficit developing between 4 and 5 years of age, with sight of the hands, may be underpinned by a developing optimization of the ways in which multisensory bodily information is used to guide (and streamline) localization when the body and limbs are in canonical postures (see Pagel et al., 2009, for a similar suggestion).

This study has established that from at least 4 years of age (and likely much earlier) children automatically locate tactile stimuli to locations on their limbs in external spatial coordinates, rather than just relative to anatomically defined locations on the body surface. But children's ability to locate touches on the body also seems to be affected by visual information concerning the limb being touched. We found that at 4 years, seeing the hands actually had an adverse effect on tactile localization when the hands were in typical (uncrossed) positions (i.e., when the body and limbs were in a canonical layout). We interpret this paradoxical finding as being due to a difficultly in early childhood with combining visual information about the body into the body schema, which is subsequently resolved by 5- and 6-year-olds. Our findings reveal that the seemingly simple task of locating a touch on the body is underpinned by a multitude of complex multisensory interactions many of which are already present by early childhood, but which continue to develop beyond 4 years of age.

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# FOOTNOTES

1. Due to an oversight, there were not enough participants in our 4-year-old group to fulfill the 24 different counterbalancing sequences. However, the counterbalancing order did not impact on children's tactile location discrimination ($p = .73$).

2. Many studies in the literature interpret crossed-hands deficits as being due to a conflict between the locations of a touch in anatomically defined coordinates (i.e., a location on the skin surface), and a location in external space (e.g., Pagel et al., 2009; Shore et al., 2002). An alternative is that tactile events are always encoded to an external frame of reference, but that poorer performance in the crossed hands posture is due to conflict between the current and the usual location of the touch in external spatial coordinates (e.g., Kitazawa, 2002). As adults our hands tend to occupy the ipsilateral side of space (Howard, Ingram, Körding & Wolpert, 2009). This may be particularly the case in infancy when infants are much less likely and willing to adopt the crossed-hands posture (Carlier, Doyen & Lamard, 2006; van Hof, van der Kamp & Savelsbergh, 2002; Provine & Westerman, 1979; Morange-Majoux, Peze & Bloch, 2000). Both accounts necessitate an ability to code tactile events in external spatial coordinates.

# TABLE CAPTIONS

Table 1: Participant characteristics.

Table 2: Results from one sample t-tests comparing children's tactile localisation accuracy with 50% (chance performance), across age groups and experimental conditions.

# FIGURE CAPTIONS

Fig. 1: The experimental set up with hands crossed and visible. In other conditions of the study we varied whether the participants' hands were crossed or uncrossed and covered or visible.

Fig. 2: Mean tactile localization accuracy (percentage correct) of 4 to 6-year-olds in the crossed-hands and uncrossed-hands posture. Error bars indicate the standard error of the mean. Panel A indicates performance in the Hands-covered condition. Panel B shows performance in the Hands-visible condition.

Fig. 3: Individual tactile localisation accuracy scores (percentage correct) of the 4-year-olds in the Hands covered and Hands visible conditions. Panel A indicates performance in the Uncrossed-hands condition. Panel B shows performance in the Crossed-hands condition. Some participants performed at the same accuracy levels across View conditions in the crossed-hands posture (see 'same score in visible and covered conditions' in the legend).

Table 1

| Age group (years) | n | Gender split | Mean age (years) | SD of age (years) |
|---|---|---|---|---|
| 4 | 22 | 11m, 11f | 4.52 | .24 |
| 5 | 25 | 19m, 6f | 5.57 | .27 |
| 6 | 30 | 13m, 17f | 6.42 | .25 |

Table 2

| Age (years) | View condition | Posture | t(df) | p | d |
|---|---|---|---|---|---|
| 4 (*n* = 22) | Visible | Uncrossed | 7.75(21) | <.001 | 2.37 |
| | Visible | Crossed | 7.55(21) | <.001 | 1.53 |
| | Covered | Uncrossed | 11.1(21) | <.001 | 1.65 |
| | Covered | Crossed | 7.19(21) | <.001 | 1.61 |
| 5 (*n* = 25) | Visible | Uncrossed | 27.55(24) | <.001 | 5.07 |
| | Visible | Crossed | 11.80(24) | <.001 | 3.26 |
| | Covered | Uncrossed | 25.34(24) | <.001 | 5.51 |
| | Covered | Crossed | 16.29(24) | <.001 | 2.36 |
| 6 (*n* = 30) | Visible | Uncrossed | 39.78(29) | <.001 | 7.47 |
| | Visible | Crossed | 23.64(29) | <.001 | 4.27 |
| | Covered | Uncrossed | 40.29(29) | <.001 | 7.26 |
| | Covered | Crossed | 25.35(29) | <.001 | 4.32 |

Figure 1

Figure 2

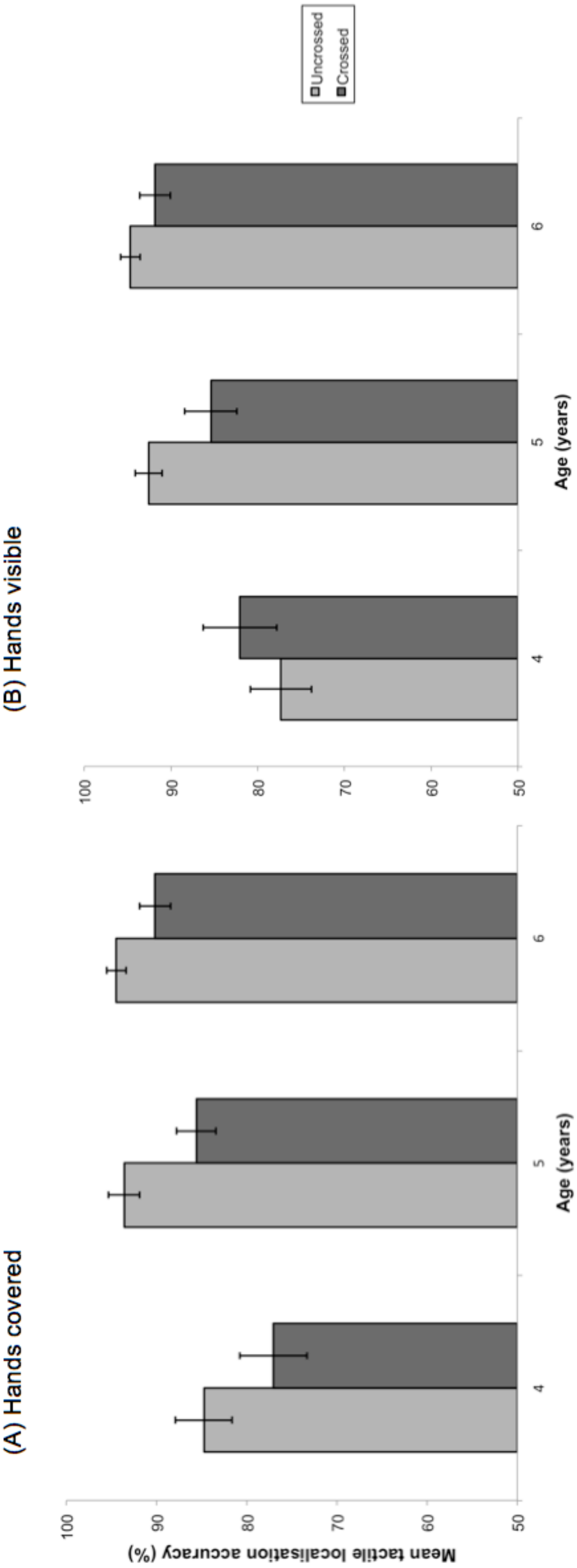
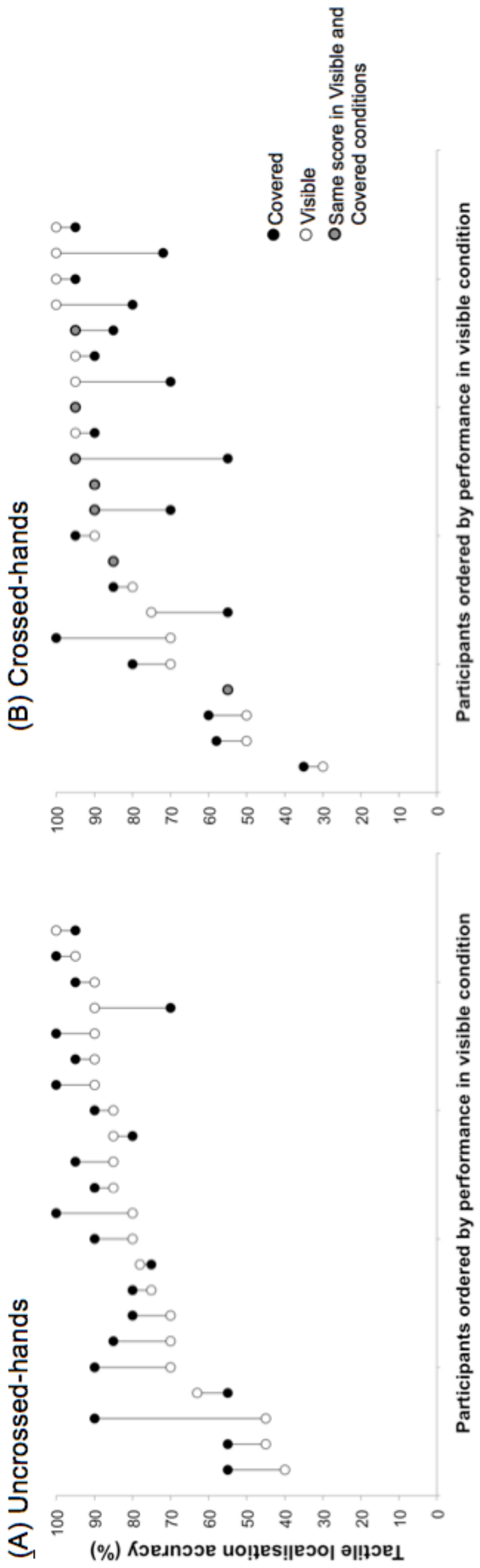

(A) Hands covered
(B) Hands visible
Mean tactile localisation accuracy (%)
100
90
80
70
60
50
4
5
6
Age (years)
Uncrossed
Crossed

Figure 3


(A) Uncrossed-hands
(B) Crossed-hands
Tactile localisation accuracy (%)
100
90
80
70
60
50
40
30
20
10
0
Participants ordered by performance in visible condition
Participants ordered by performance in visible condition
● Covered
○ Visible
● Same score in Visible and Covered conditions