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Intermanual Transfer of Shapes in Preterm Human Infants From 33 to 34 + 6 Weeks Postconceptional Age

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This study investigated the ability of preterm infants to learn an object shape with one hand and discriminate a new shape in the opposite hand (without visual control). Twenty-four preterm infants between 33 and 34 + 6 gestational weeks received a tactile habituation task with either their right or left hand followed by a tactile discrimination task in the opposite hand. The results confirmed that habituation occurred for both shapes and both hands. Infants subsequently held the novel shape longer in the opposite hand. The results reveal that preterm infants are capable of intermanual transfer of shape information. In spite of the immaturity of the corpus callosum in preterm infants, its development seems to be sufficient to allow some transfer of information between both hands.

The somatosensory system is the first sense to develop during embryogenesis. To describe the gradual establishment of cutaneous receptors during this period, researchers studied the responses of aborted fetuses after tactile stimulation on different parts of the body (Hooker, 1938, 1952; Humphrey, 1964, 1970). The development of cutaneous receptors begins from the 7th week of gestation. The parts of the body which react to tactile stimulation are the area around the mouth (8.5 gestational weeks [GW]), the genital area (10.5 GW), the palms of the hands (between 10.5 and 11 GW), and the soles of the feet (12 GW). Lastly, the skin receptors are present throughout the body surface up to 20 GW. Moreover, pressure exerted on the palm of the

hand by an object or even the observer's finger (grasping) triggers the closing of the fingers around the stimulus and appears around 18 GW (Hooker, 1938). Recent studies revealed that the grasping at birth is not only a pure reflex (Hernandez-Reif, Field, Diego, & Lergie, 2001; Molina, Guimpel, & Jouen, 2006; Molina & Jouen, 1998, 2004; Rochat, 1987; Streri, Lhote, & Dutilleul, 2000). Manual exploration of the objects would allow the newborn to gather information about them. Using a classic habituation–reaction to novelty procedure (without visual control), Streri et al. (2000) showed that full-term newborns, tested at 2 days of age, were able to memorize tactile information about specific shape features (prism or cylinder) and detect differences between these two shapes with either the right or left hand. Similar abilities have been found in preterm infants from 33 to 34 + 6 GW (Lejeune et al., 2010) and were not influenced by hand, shape and preterms' medical history.

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The present research investigated the ability of preterm human infants to transfer shape information from one hand to the other (without visual control). Two main reasons for interest in intermanual transfer have to do with the assessment of the communication between the two hemispheres and cerebral plasticity during the cognitive development. Sann and Streri (2008) investigated the intermanual transfer of shape in twenty-four 2-day-old full-term newborns. After tactual habituation to a shape (prism or cylinder) in one hand, full-term newborns held the familiar shape longer in the opposite hand, and not the novel shape as usually expected in such a procedure (Soroka, Corter, & Abramovitch, 1979). But in the same study, infants also exhibited intermanual transfer of texture (smooth or granular) with a preference for the novel texture in the opposite hand. According to Sann and Streri (2008), these discrepancies in performance between object properties indicate that the property of shape requires a "higher and more elaborate representation" relative to texture. However, given the design of the study, it is not possible to draw definite conclusions about the type of shape information that transferred: the entire shape of the object, edge information (round vs. angled), or other contrasts or differences. Regardless, these results provided evidence of intermanual transfer of shape in full-term newborns with the hypothesis that the development of the corpus callosum would be sufficient to permit some transfer of shape information between the two hands. Indeed, an fMRI study demonstrated the essential contribution of posterior corpus callosum to the interhemispheric transfer of tactile information (Fabri et al., 2001, 2005). Considering that the corpus callosum is less mature in preterm infants than full-term infants (Anderson, Laurent, Woodward, & Inder, 2006) and that very preterm birth (before 33 GW) might be associated with perinatal brain injury including the corpus callosum (Kontis et al., 2009), we wanted to determine if preterm infants are capable of intermanual transfer of shape after the age of 33 GW.

The main purpose of this study was to investigate the interhemispheric transfer of shape information. We employed a habituation–dishabituation procedure without visual control. After habituating to an object in one hand, half of the infants received the familiar object then the novel object, and the other half received the novel object then the familiar one, in the opposite hand. First, we expected that after successive presentations of the same object, there would be a decrease in the holding

time evidenced by each preterm infant regardless of the tested hand or the object's shape, confirming our previous results regarding the presence of a habituation process in very young infants. Second, the hypothesis of discrimination in intermanual transfer would be confirmed by differential treatment of novel and familiar objects in the opposite hand, as demonstrated previously in full-term newborns (Sann & Streri, 2008). Thus, we defined discrimination as having occurred when the mean holding time for the novel object and the mean holding time of the familiar object in the opposite hand differed significantly. Third, because habituation and test phases did not involve the same hand, we conducted another analysis contrasting the last two habituation trials and the test trials to strengthen the discrimination results, as well as to assess if change of hand, regardless of the type of object presented, affected discrimination. Relative to the last two habituation trials, we expected that a differential increase of holding time in the opposite hand would depend on the type of object presented (novel or familiar).

Method

Participants

The participants were 24 preterm infants (13 girls and 11 boys) hospitalized in intensive and regular neonatal care units in the hospital of Grenoble (France). At birth, the mean gestational age was 30 weeks and 2 days (range = 26 + 3 to 33 + 4 weeks) and the mean weight was 1419 g (range = 800 to 2265 g.). When the preterm infants were tested, the mean postconceptional age was 34 weeks and 3 days (range = 33 + 2 to 34 + 6 weeks), the mean postnatal age was 29 days (range = 9 to 55 days), and the mean weight was 1752 g (range = 1180 to 2190 g.). The preterm infants had to possess the grasping reflex, to not be affected by a polymalformative syndrome, to have a normal cranial ultrasonography, and to not be given sedative or anticonvulsive treatment during the experiment. Participants came from middle- to upper-middle-class Caucasian families. Parents gave written consent for their baby to participate in the experiment. An additional participant was eliminated from the study because of crying. The present study was conducted in accordance with the Declaration of Helsinki and approved by the local ethic committee of the LPNC (CNRS and University of Grenoble 2). The experiment was classified as purely behavioral and the testing involved no discomfort or distress to the infants.

Display and Apparatus

Each preterm infant was tested in his incubator just before or just after care, in an Arousal State 4 of Brazelton scale (Brazelton & Nugent, 1995) and more than 1 hr after being fed. Because an arousal state is difficult to assess with an absence of training in close observation of the newborn, only two paediatricians and a psychologist were assigned to conduct the experiments. Consequently, it was not possible that experimenters were blind to the hypotheses. The first experimenter installed the infant in a semi-upright position during the entire experiment and positioned his head on the opposite side of the tested hand, so that the infant could not see the test object. The second experimenter recorded holding times of objects with a hand-held computer that calculated a rate of habituation for each infant, trial after trial. Interobserver reliability was not feasible during testing because there could not be more than two experimenters in the preterm's room for evident ethical reasons governing a neonatal unit. However, the experiment was videotaped to be analyzed a posteriori to verify the holding times recorded by the hand-held computer and to control experimenter bias. Interobserver reliability was high (Pearson's $r = .95$). The stimuli were a cylinder (a smoothly curved shape) and a prism (a sharply angled shape). These objects were chosen due to their inclination to easily trigger the palm grasp reflex. The cylinder was 35 mm long and 6 mm in diameter, and the prism was 35 mm long and had a $9 \times 6 \times 6$ mm triangle base. The objects used in the trials were identical to those used by Sann and Streri (2008) although smaller because preterms' hands are smaller than full-terms' hands. The object to hand ratio was identical.

Procedure

Habituation phase. The first experimenter put an object in either the infant's right or left hand and the first trial started. The experimenter had to hold the preterm's forearm in order to cope with hypotonia

(reduced muscular tonus). When the infant grasped the object, the second experimenter began recording the holding time. Once the preterm infant released the object after having held it for at least 1 s, the experimenter stopped the recording and ended the trial. If the preterm infant held the object for 60 s, the first experimenter gently opened the infant's hand and removed the object, ending the trial. After an inter-trial interval of about 10 s, the experimenter presented the object again, beginning another trial. Habituation trials continued until the duration of holding on any two consecutive trials, from the third trial onward, totalled a third or less of the total holding time of the first two trials. If our criterion of habituation was not met by the 12th trial, the infant was excluded from the experiment. Two groups were made according to the hand in which the object was put during the habituation phase, and then two subgroups were made according to the object's shape used during the same phase. The infants were randomly assigned to these four groups.

Test phase. Immediately after habituation (just in time for the experimenter to move to the other side of the incubator), four test trials were conducted. The objects were put in the opposite hand of the one tested during the habituation phase. Infant were given the familiar object for two consecutive trials and the novel object for two consecutive trials. The order of presentation of the two objects was counterbalanced between infants.

Results

Habituation phase

Four parameters of performance were measured: mean total holding times occurring until the habituation criterion was reached, mean holding times of the first two trials, mean holding times of the last two trials and mean number of trials conducted. Table 1 presents the main characteristics of habituation. First, the results revealed that

Table 1
Characteristics of Habituation (Means and Standard Deviations) According to the Hand (Right or Left) and to the Object (Prism or Cylinder)

Hand	Shape	Total holding time (s)	First two trials (s)	Last two trials (s)	No. trials
Right	Prism	91.6 (18.3)	58.8 (25.3)	7.5 (3.1)	4.8 (1)
	Cylinder	139.7 (53.3)	75.1 (26)	9.3 (4.7)	5.8 (1.9)
Left	Prism	108.2 (73.7)	40.3 (26.2)	3.8 (3.3)	6 (0.9)
	Cylinder	83.5 (55.5)	39.9 (19.3)	4 (2.9)	5.3 (1.4)
Total		105.8 (55)	53.5 (27.2)	6.2 (4.1)	5.5 (1.4)

habituation was present for each preterm infant. No infant failed to habituate: Each infant met the criterion of habituation before the 12th trial.

Secondly, to ascertain whether the habituation measures were affected by hand and shape, a 2 (hand: right vs. left) \times 2 (shape: prism vs. cylinder) analysis of variance was performed for each parameter of performances. First, for the mean total holding times, there were no significant effects for the Hand factor, $F(1, 23) = .803$, $p = .381$; Shape factor, $F(1, 23) = .280$, $p = .603$; and the Hand \times Shape interaction, $F(1, 23) = 2.721$, $p = .115$. Second, for the mean holding times of the first two trials, the analyses revealed a main effect of the hand factor, $F(1, 23) = 7.261$, $p = .014$. Thus, preterm infants held objects with the right hand ($M = 67$ s, $SD = 26$) longer than with the left hand ($M = 40$ s, $SD = 22$) during the first two trials of habituation, but there were no significant effects for the shape factor, $F(1, 23) = .636$, $p = .434$, and the Hand \times Shape interaction, $F(1, 23) = .699$, $p = .413$. Third, for the mean holding times of the last two trials, the analyses revealed a main effect of the hand factor, $F(1, 23) = 9.690$, $p = .05$. Thus, preterm infants held objects with the right hand ($M = 8.4$ s, $SD = 4.9$) longer than with the left hand ($M = 3.9$ s, $SD = 3$) during the last two trials of habituation, but there were no significant effects for the shape factor $F(1, 23) = .484$, $p = .495$, and the Hand \times Shape interaction, $F(1, 23) = .313$, $p = .582$. Finally, for the mean number of trials, there were no significant effects for the hand factor, $F(1, 23) = .360$, $p = .555$; shape factor $F(1, 23) = .090$, $p = .767$; and the Hand \times Shape interaction, $F(1, 23) = 2.252$, $p = .149$.

Test Phase

First, individual analysis revealed that 18 infants (9 with the right hand and 9 with the left hand) held the novel shape longer and 6 infants (3 with the right hand and 3 with the left hand) held the familiar shape longer ($p < .05$, sign test). This result indicates a systematic preference for the novel object. Second, a 2 (order: novel–familiar vs. familiar–novel) \times 2 (test trials: familiar vs. novel) \times 2 (hand: right vs. left) analysis of variance was performed for the holding times with order and hand as between-subjects factors and test trials as a within-subjects factor. Results showed no significant effects of the order, $F(1, 20) = .098$, $p = .758$, and hand factors, $F(1, 20) = .109$, $p = .744$, and a significant effect of the test trials factor, $F(1, 20) = 7.705$, $p = 0.012$: Preterm infants held the novel shape longer ($M = 23.5$ s, $SD = 17$) than the familiar one ($M = 14.2$ s,

$SD = 14$). Results also indicated a significant Order \times Hand interaction, $F(1, 20) = 4.451$, $p = .048$. Preterm infants held both objects longer with their right hand ($M = 22.8$ s, $SD = 19.4$) than with their left hand ($M = 13.3$ s, $SD = 15.6$) when the novel object was presented first. However, they held both objects longer with their left hand ($M = 26.2$ s, $SD = 15.8$) than with their right hand ($M = 13.2$ s, $SD = 10.2$) when the familiar object was presented first. No significant interactions of Test Trials \times Order, $F(1, 20) = .294$, $p = .594$; Test Trials \times Hand, $F(1, 20) = .246$, $p = .625$; and Test Trials \times Order \times Hand, $F(1, 20) = .689$, $p = .416$, were found. Consequently, the significant Order \times Hand interaction did not influence the discrimination process revealed by the significant test trials effect. In short, the results suggest that a reaction to the novel shape was obtained in preterm infants, and neither the order of presentation nor the tested hand influenced this preference.

To assess if the change of hand could affect discrimination, a second analysis of variance was conducted with the phase as a within-subjects factor (last two habituation trials vs. two novel test trials vs. two familiar test trials) for the holding times. The analysis revealed a main effect of the phase factor $F(2, 46) = 14.138$, $p < .001$. Figure 1 illustrates the results. Planned comparisons were then conducted to examine differences in holding times between the habituation phase and test phase according to the nature of the object (novel or familiar). First, these comparisons showed that infants held the novel object ($M = 23.5$ s, $SD = 17$) in the opposite hand significantly longer during the test phase than during the last two habituation trials ($M = 6.2$ s, $SD = 4.1$), $F(1, 23) = 25.371$, $p < .001$. Second, the analyses revealed that infants held the familiar object ($M = 14.2$ s, $SD = 14$) in the opposite hand significantly longer during the test phase than during the last two habituation trials ($M = 6.2$ s, $SD = 4.1$), $F(1, 23) = 6.648$, $p = .017$. Thus, preterm infants held novel and familiar objects longer in the opposite hand, compared to the last two habituation trials, but the increase between the two phases was significantly greater for the novel object than for the familiar one, $F(1, 23) = 8.348$, $p = .008$.

Discussion

The aim of this research was to investigate the ability of preterm infants to transfer shape information from one hand to the other. First, the results confirmed the presence of haptic manual habituation

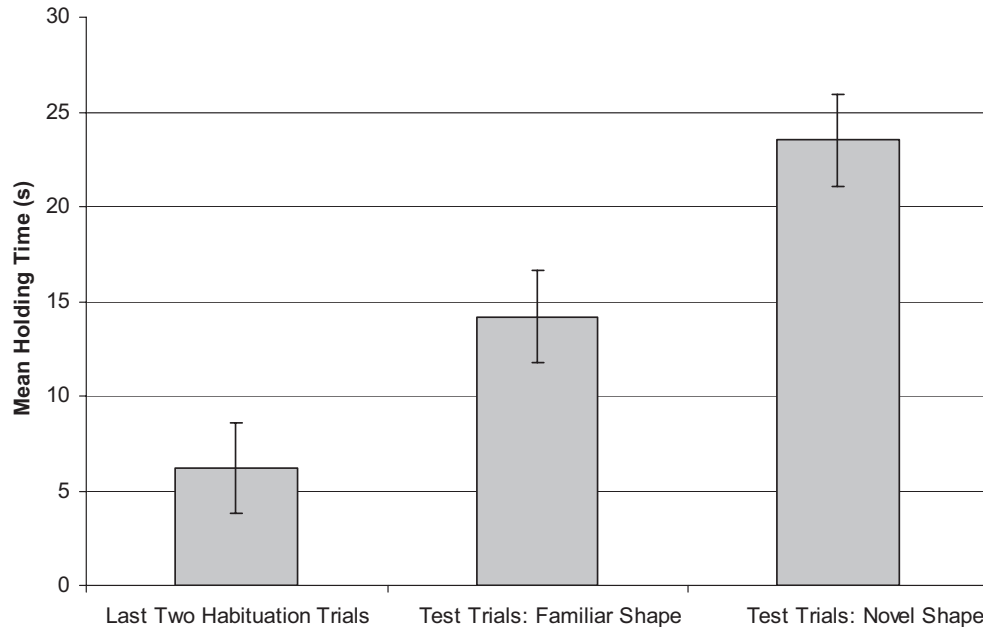


Figure 1. Mean holding times in seconds and standard errors during the last two habituation trials (in one hand) and during the test trials for the novel and the familiar objects (in the opposite hand).

for each hand and for each shape in preterm infants between 33 and 34 + 6 GW. However, contrary to our previous study with 24 infants and an identical habituation procedure (Lejeune et al., 2010), a main effect of hand was observed for two parameters of habituation: Preterm infants held objects with the right hand longer than with the left hand during the first two and the last two trials of habituation. Even if few similar asymmetries have previously been found, they suggest in some samples stronger grasping with the right hand (Caplan & Kinsbourne, 1976; Petrie & Peters, 1980). Nevertheless, regarding the other parameters of habituation (total holding time and number of trials), no other effect of hand was significant. Moreover, during the test phase, the analyses did not reveal any influence of the hand on performance. This specific hand effect is difficult to explain and could be the reflection of interindividual variability. However, the presence of haptic manual habituation, in relation to the results of the test phase, means that preterm infants are able to encode some information about the shape of an object with each hand.

Second, the main result of the present experiment was that after habituation to the shape of an object in one hand, preterm infants held the novel object longer in the opposite hand. For the first time, these results indicate that intermanual transfer of shape is present in preterm infants between 33 and 34 + 6 GW. Fabri et al. (2005) showed the

essential contribution of posterior corpus callosum to the interhemispheric transfer of tactile information, so its development seems to be sufficient to permit the transfer of some shape information between both hands in preterm infants between 33 and 34 + 6 GW. However, preterm infants increased their holding time in the opposite hand with both novel and familiar objects, although this increase was significantly greater for the novel object than for the familiar one. While the increase of holding time was expected for the novel object, confirming the presence of discrimination, the increase of holding time for the familiar object was more surprising.

This second result provides information about the influence of changing hands on manual discrimination. This pattern of results could be due to two factors, one peripheral and one central. At a peripheral level, the tactile receptors were not the same as those stimulated during habituation and the information collected by the opposite hand had to be sent to the central nervous system by another pathway. In addition, given that the infant participants had underdeveloped muscle tone, the increase in holding time could also be caused by muscle fatigue in the habituated hand, compared to the unfatigued contralateral hand. Any form of tactile stimulation of the contralateral hand would induce some degree of recovery from habituation. At a central level, the comparison of object

information collected by both hands required more time than during intramanual discrimination. The increase of holding time could reflect the time required to transfer information between the two hemispheres via the corpus callosum.

Finally, the direction of preference (novelty preference) differed from that observed in 2-day-old full-term newborns with a similar procedure. Two interpretations are possible. First, because it is impossible to determine what type of shape information was transferred (entire shape, edge information, or other contrasts or differences), one possible interpretation could be that full-term and preterm infants might process different types of shape information, leading to this discrepancy of preference. A second interpretation could be that in this task context, experience would prevail over maturation. In fact, preterm infants were tested at an earlier post-conceptual age (34 + 3 GW) than full-term newborns (40 + 2 GW) but at a later postnatal age (30 days vs. 2 days). Consequently, our results could be explained by greater tactile experience *ex utero* than for full-term newborns. However, 2-month-old full-term infants still demonstrate a familiarity preference (Streri, Lemoine, & Devouche, 2008) while their postnatal age was greater than that of our preterm infants. To explain this second discrepancy, the type of tactile experience might be a second factor, with the length of experience influencing the direction of preference. Indeed, preterm infants in their incubators receive lots of repetitive and stereotyped tactile stimulation (daily care, alimentation, medical examinations, etc.). Hospitalized infants experience up to 14 painful procedures per day and up to 53 different procedures during their first 15 days of life (Simons et al., 2003). Furthermore, Gimenez et al. (2008) showed that maturation of brain tissues may be accelerated by factors associated with preterm birth, perhaps directly by the effects of the extrauterine environment. These particular tactile experiences could enhance the development of the intermanual transfer of information in preterm infants. In this case, according to the hypothesis proposed by Sann and Streri (2008), it would mean that preterm infants could have a more elaborate representation of shape than full-term newborns, leading to a preference for the novel shape in the opposite hand. However, these interpretations remain speculative and require further investigation. More generally, in the infancy literature, the explanation of direction of preference is still debated and seems to depend on several factors (Pascalis & De Haan, 2003). Whatever the direction, the existence of a

preference in these studies indicates the presence of discrimination and suggests that the development of the corpus callosum would be sufficient to permit some transfer of shape information between the two hands in preterm infants from 33 GW.

In conclusion, the present study has shown for the first time that intermanual transfer of shape information is present at 33 GW in preterm infants. Further investigations are needed to better understand the reasons for discrepancies in the direction of preference (novel vs. familiar) as a function of an object's properties, postnatal age and tactile experience.

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