Body representation and spatial abilities of preterm low birth weight preschool children

Beatrix Lábadi (labadi.beatrix@pte.hu)
Institute of Psychology, University of Pécs, Ifjúság u. 6. Pécs, 7627 Hungary
Enikő Györkő
Institute of Psychology, University of Pécs, Hungary
Anna Beke
Obstetrics and Gynaecology Clinic No.1, Semmelweis University, Budapest, Hungary

Abstract

The goal of the present study was to investigate the relationship between spatial ability and development of body representation in preterm low birth weight preschool four-year-old children without neurological deficit and typically developing children who were matched by IQ and chronological age. Our findings indicate that children born prematurely with a normal cognitive level may have specific difficulties in all levels of body representation which may be associated with the spatial language production. These finding are relevant for understanding the qualitative aspects of body representation and provide practical consequences for early intervention of children born prematurely.

Keywords: body representation, spatial memory, spatial language, preterm born

Introduction

Over the past decades, rapid development in the perinatal and neonatal care has increased the survival rate of children who are born very premature, however, there are potential risks for long-term morbidity. Indeed, children born preterm with low birth weight often have neuromotor problems and are at risk for deficit in cognitive abilities in such neuropsychological domains as memory, attention, executive function and language (Mikkola et al. 2005; Marlow, Henessy, Bracewell & Wolke, 2007). The longitudinal studies emphasize that preterm birth with low birth weight have long-lasting negative impact on the cognitive abilities and academic skills in school-aged children (Conley & Bennet, 2000). However, cognitive impairments often cannot be detected clearly until these children begin school.

Most psychological studies of cognitive functioning of preterm children investigated the deficit in general domains such as global intelligence, attention, perceptual-motor functioning, executing functioning and memory. These assessments demonstrated that children born preterm have worse neuropsychological outcomes relative to typically developed children. Relatively small number of studies focused on the specific patterns of the cognitive abilities of preterm children such as spatial abilities, and none of these studies investigated the specific impairment in body representation. Some studies reported that being born prematurely with low birth weight is a risk for deficit in spatial memory span and spatial working memory, as well as recognition memory (e.g., Georgieff & Nelson, 2002).

Recently an extensive interest has been shown about the role of bodily experience in cognitive processes. However, there has been a widespread confusion about the nature of the mental representation of body (Gallagher, 1986) mostly due to the variability of existing taxonomies and models. According to the growing consensus in the field of neuropsychology (Sirigu, Grafman, Bressler, & Sunderland, 1991) as well as in developmental psychology (Slaughter & Heron, 2004) the three-level model is supported which distinguishes (a) a sensori-motor representation of the body; (b) a visual-spatial body representation; and (c) a lexical-semantic representation of the body. The sensori-motor level consists of a short-term online representation of the body which is responsible for body movement and not accessible to consciousness. The visual-spatial representation consists of long-term and general knowledge about the body topography including the spatial localization of body parts. The lexical-semantic representation involves the general knowledge of the body and its functions involving the naming of body parts or semantic knowledge about the body functions e.g. biological background. The latter two levels of body representation are accessible to consciousness.

The available studies suggest that infants begin learning about their bodies as newborns, but at that time they create only a highly schematic representation of human body (Quinn & Eimas, 1998). The detailed visual-spatial representations of human body emerge around 15- to 18 months when they are capable to discriminate scrambled human body image from non-scrambled body image (Slaughter & Heron, 2004). Interestingly, visual-spatial representation of faces emerges earlier than body representation; even newborns are able to discriminate human faces from scrambled faces (Johnson & Morton, 1991), infants are likely to be born with an innate schema of human faces rather than a human body. The detailed visual-spatial representation becomes available from the second or third year of life when children begin to develop an explicit representation of the body and recognize the human shape with its distinctive configuration and spatial topography (Brownell, Nichols, Svetlova, Zerwas & Ramini, 2010).

Based on the previous studies the visual-spatial representation of the body is likely to derive from sensori-motor representation. This early bodily experience is the root of the developing body representation, cognitive abilities as well as the self. The body awareness is not a sort of separated entity in the world; rather it is a relational between the body and either the physical and social environment (Rochat, 2010). Even newborns begin to develop the implicit bodily self which is embedded in their environment. Shortly after the birth neonates begin to learn the relation between their current capacities (e.g. motor skills, bodily constraints) and the environmental conditions. But an important question is raised whether children who are born very prematurely before 30 gestational weeks and spend their first month(s) in a sensory deprived environment are able to develop a typical body representation.

Present study

Children who were born prematurely and spent their first weeks in incubator as a part of the intensive care have been frequently reported deficit in sensori-motor domain. The lack of early physical contact with the world prevents them from collecting experience from their own bodies which might specifically impact on the later body knowledge and related cognitive abilities.

This study was designed to answer specific questions about different aspect of body representation in prematurely born children aged between 4 to 5 years. There are both practical and theoretical reasons for addressing the questions of body representation. From a theoretical point of view, the research attempts to provide further evidence for the childhood development of body representation and its relation to spatial cognition. The practical aspect of the research is to provide deeper insights into the possible deficit of body representation in preterm children for early educational and rehabilitative intervention to improve the preterm children's cognitive and behavioral outcome.

Method

Participants

We studied 31 preterm children aged between 4 and 5 years, who were born before 30 gestational weeks (Mean: 27.93 weeks, SD: 1.63; ranging from 25 to 30 gestational weeks) and their birth weight ranged from 600 g to 1680 g (Mean: 1040g, SD: 241 g). Additional 12 children were discarded because of fussiness (N =4) or incomplete task performance on more than 3 tasks (N=8). Preterm children were enrolled via the Department of Pediatric Neurology at the Obstetrics and Gynaecology Clinic No.1 of Semmelweis University in Budapest. Prior to the study children were assessed by a clinical neuropsychologist and a pediatric neurologist who ensured that children are within the normal range of intellectual abilities without neurological symptoms, however they are in the lower part of the normal range as the most of the very preterm children (< 30 gestational week). The inclusion criteria for preterm children were the following: (1) birth at a gestational age of 30 weeks or younger; (2) no congenital abnormalities; (3) no measurable neurological deficit; (4) no retinopathy or prematurity; (5) no mental, intellectual disabilities.

The control group included children born at term having no history of perinatal problems. The full-term children with typical developing characteristics (N=26) were born after 38 gestational weeks and individually matched with the preterm sample for age, parents education and IQ (Hungarian version of Brunet-Lezine Test). Full-term children were recruited from the local preschool selected by teachers on the average level of the class.

Materials and Procedure

General procedures took place in a quiet lab. Each child was tested individually. Three tasks were conducted to assess body representation of children and additional two tasks evaluated children's spatial abilities.

Tasks for body representation

Sensori-motor body representation - Fitting hands task. Here, we investigated children's ability to reason about their body size, and shape relative to the objective physical world. In this task children were required to use their own sensori-motor body representation while fitting their actions to the visual-spatial patterns of the world. Nevertheless, our task included only the hands and it did not extend to the whole body. This task required the child to insert their hand into one of two apertures to take out a toy from a box. The apertures were placed on the top of a box and varied due to different visual-spatial patterns. To be able to solve the task, the child required to recognize the spatial relationship of a visual pattern of the aperture and his/her own body properties and the bodily action. First, the child had to analyze the perceptual constraints of the apertures then compare them with their own hands properties. Finally, they were required to choose the correct aperture, orient and adjust their hands to the size, orientation and the shape of the aperture in order to insert one hand into the box.

In this task we used a box (20 x 30 x 15 cm) with different interchangeable lids. The size of the apertures was adjusted to a typical 5-year-old child's hand size. Each lid had two apertures which varied within three dimensions: size, shape and orientation. The apertures were presented side by side on the lid and one of two apertures violated the physical constraints, therefore children were prevented from inserting their hands into this aperture, for example the aperture was smaller than the child's hand. Each child performed 9 trials (three per dimension) and the order of the stimuli was randomized.

The experiment was recorded and the tapes were time-coded by digital clock. The hand actions were also coded and analyzed by two independent raters for the purpose of assessing successful choice, reaction time and qualitative analysis of hand laterality.

Visual-spatial body representation - Scrambled body task

To investigate the visual-spatial body representation we reproduced scrambled body images used by Slaughter, Heron & Sim (2002). However, we modified them by using friendlier children figures instead of adult pictures, and we also changed the presentation method. We used a pairwise comparison method with two sets of human body pictures, one for typical body and another for scrambled body. Each set consisted of 6 six images, these were black and white line drawings. The scrambled body set violated the typical canonical human body shape, for example legs attached to the shoulders or arms attached to the hip. The pairings of typical and scrambled figure pictures and the side of presentations were randomized across children. The children were asked to decide which picture showed a typical body. We measured the correct responses and analyzed the typical errors.

Lexical- semantic body representation - Body part localization task

This task investigated children's ability to locate their body parts on themselves. The task was adopted from adult studies examining the body representation deficits in adults with focal brain damages. Children were asked to point to their own body parts as the examiner named them. This task was divided into two parts, one of which referred to the naming of the head parts and the other requested naming the other body parts (we determined 7 standard locations on the head and 24 locations on the body). The whole procedure was recorded and two independent trained raters coded the performance (within these categories: correct location, different body part, refuse). Interraters reliability was .93.

Tasks for spatial abilities

Spatial memory. The spatial memory task was adopted from the Hungarian Version of Snijders – Oomen Nonverbal Intelligence Scale for Young Children. This subtest assesses the spatial location memory in young children. The participant is presented with a little house shape made of paper with six or ten windows depending on the trials. The windows represent the hiding locations, which are displayed in three horizontal rows with 6 windows, and L-shaped configuration with ten windows, where these extra four windows are added to one side of the house. In each trial, the experimenter places a black kitten made of paper into one of the windows then quickly closes all windows and covered the place with a screen for 6 s. When the screen is removed the children are immediately being requested to point the window where the kitten was hid. The number of the correct responses was computed for the analysis.

Spatial language production

Hungarian language has many possibilities to encode spatial relations: suffixes, postpositions, verbal prefixes and adverbs (Lukács, Pléh, & Racsmány, 2007). In this study we focus on postpositions that are used to encode cognitively complex relations and postpositions providing cue to encode the path type in three different forms according to the dynamic aspect of coding the location and the path. For each spatial relation, Hungarian has a static locative term, and two dynamic forms, one encoding the goal or end of the path; and the other relates to the source or starting point of the path. All three types can be distinguished linguistically but the same complexity provides good grounds for testing path type effects on spatial language use, which is not available in all languages - for example, English often uses the same postpositions for static and goal relations.

Fig. 1. Spatial layout in the spatial language task

In our study the spatial terms were elicited in an experimental space consisting of a 1.5 x 1.5 m matrix involving a white mug divided into 16 identical squares with black lines (Fig. 1). We also used five little wooden chairs made for children with different tops representing animals (e.g. monkey) and fruits (e.g. pumpkin) as reference objects. During the experiment these chairs were placed into the matrix, while children were requested to answer 3 types of questions encoding the path e.g. *'Where is the monkey?'* (static); *'Where do I put the melon?'* (goal); *'Where do I take the apple from?'* (source). We tested the spatial term production within either egocentric or allocentric frame of reference. The experimenter was standing outside of the matrix and put the target object (chair) to different positions related to either one or two other objects (chairs) or the child depending on the spatial frame of reference. In the allocentric situation the child stood outside of the matrix and he/she was required to respond to the experimenter's questions referring to the relations among the objects (e.g. *'The apple is next to the melon'*). While in the egocentric situation child sat in the centre of the matrix on a chair and requested to answer the question from his/her egocentric viewpoint (e.g. '*The apple is next to me'*). Altogether 12 postpositions were tested in each situation. Children's scores were computed according to the number of correct 'spatial postposition' productions.

Results

Sensori-motor body representation - Fitting hands to a visual form task. The hand actions were analyzed due to the number of correct choices and action duration.

Correct insertion: For each trial, the correct attempts to insert the hand into the aperture were coded and calculated as a correct choice, but it was only the first attempt that was counted. A repeated measures of ANOVA with visual-spatial features (form, size and orientation) as the within subjects factor and groups (preterm and full-term) as the between subject factor was conducted on the scores of the correct responses. No significant difference was found between the groups (F (1, 50) = 1.198 p =ns.). But a significant effect emerged for visual-spatial feature (F (1, 50) = 26.162, p < .000), namely, children tended to perform better in trials of orientation than form or size trials. No significant interaction between the group and visual-spatial features was found.

Time: we registered the overall duration of action, the time from the appearance of the novel lid until the child took out the toy from the box. The incorrect choices were excluded from the analysis. Repeated measures of ANOVA (2 x 3 x 3) were used to compare preterm and full-term children as between subject variable (preterm vs. full-term) and trials as well as visual-spatial features (shape, orientation and size) as within subject variables. We found significant differences between the groups for the overall reaction time (F (1, 50) = 7.609, p <.009). Preterm children (M= 3.93, SE =.198) spent more time to solve this problem than full-term children (M=3.02, SE = .193). We also found differences between the visual-spatial categories (F (2,50) = 24.433, p<.000), where the pairwise comparison showed that the orientation category (M=2.409, SE =.094) of the visual-spatial pattern of the aperture differed either from the shape (M = 4.005, SE = .205) or the size (M= 3.787, SE = .236) category. Significant interaction was found among group, trial and visual-spatial features (F (4, 50) =3.409, p <.011).

Visual-spatial body representation - Scrambled body task

We compared the performance between the preterm and full-term group based on the total scores. The analysis revealed significant differences (F (1, 60) = 4.901; p< .031). The premature children's performances were poorer (M= 5.04, SD= .79) than those of the control peers (M= 5.92, SD= .37). These differences can be described by the difficulties in the discrimination of the limbs.

Body part localization. One-way analysis of variance (ANOVA) was conducted as appropriate on the measures of both dimensions of body representation such as the head and the whole body. Significant effect for both dimensions emerged, and full-term children showed better performance either for head dimension (F (1, 47) = 11.609; p<.001) and for the whole body dimension (F(1, 47) = 28.975; p<.000). Though, the scores of head were near the ceiling in both groups (preterm: M =6.32, SD=.72; full-term: M= 6.94, SD=.24). Children in the full-term group (M=19.17, SD=2.40) exhibited higher performance than their preterm peers (M=14.22, SD = 3.27).

Spatial memory. Delayed recall score of the two groups were analyzed by a one-way analysis of variance (ANOVA). The preterm children obtained a lower score (M = 6.70 SD = 2.57) than did the control group (M=7.84, SD = 2.22), but no significant difference was found (F (1, 56) = 3.122, p= .08).

Spatial language. A repeated measures of ANOVA (Type III) for spatial language (egocentric, allocentric) as within subjects factor and for groups as between subjects factor was conducted. Significant effects were revealed for the groups (F (1, 54) = 28.635 p <.000). Children born full-term achieved more than twice as many scores as prematurely born children did. We also found differences between the conditions (allocentric and egocentric; F(1, 54) = 11.916 p<.001). In both groups children performed poorer in the egocentric condition, they could use more postpositions viewed from outside of the matrix.

Relationship between body representation and spatial abilities in preterm children. To determine whether preterm children's body representations were related to spatial abilities Pearson correlations were calculated among these variables with age partialled out from the calculation (Table1). Surprisingly, we have not found association between the performance in scrambled body task and the spatial variables. However, positive association was found between the performance in allocentric spatial language and body localization test (r = .680, p <.21); whereas the egocentric spatial language showed negative correlation with the meantime of hand action (r = -.606, p<.048). Furthermore, the egocentric spatial language showed positive association with the mean correct choices in the hand task (r = .692, p<.018). In contrast, no significant association was found between the performance in spatial memory and different levels of body representation.

Table 1 Intercorrelation among body representation and spatial ability measures in preterm children

	Spatial language Allocentric	Spatial language Egocentric	Spatial memory
Scrambled body	.404	.369	.197
Body part localization Whole body	**.680***	.103	.394
Hand fitting Correct choices	.027	**.692***	.119
Hand fitting task	.191	**-.606***	-.226

Note *df* varied from 24-29 depending on the number of children completing a given task of overall sample
*p < .05

To determine to what body representation levels are related, Pearson correlation were computed controlling for age (in months) in the whole sample. The correlations were calculated among each score of performance in each body representation tasks: scrambled body, body part localization, fitting hands. Significant correlation (see Table 5) were observed between the performance of scrambled body task and performance in both body localization tasks (for head r =.427, p <.04; r =.471, p<.04; for whole body r =.471 p<.02) as well as the scores of correct choices in hand fitting task (r=.427, p <.04). None of the variables of hand fitting task related to the outcome of other body knowledge variables. The variables of hand fitting task was associated only with each other, namely, the means of the correct responses negatively correlated with the mean time of preadjustment (r= -.545, p<.007).

Discussion

Early development of body representation comparing preterm and full-term children was investigated in the current study. We reported evidence that children born very prematurely, without major neurological deficits and with a normal cognitive level, have specific difficulties in most of the body related tasks evaluated at 4 years of age. We further found that the reduced performance in body representation is related to spatial language, but not to the spatial memory within the preterm group.

Relative to full-term controls, preterm children in the present study showed reduced performance at all levels of body knowledge. However, in the task of fitting hand, where the children are requested to rely on their sensori-motor body representation, both groups are equally good at scaling their reaching action to size, form and orientation of the aperture. By contrast, previous findings of younger children (1.5 - 2 years) showed a poor performance in a similar scaling task (Ishak and Adolph, 2008), where toddlers frequently attempted to fit their hands into the impossibly small holes. As Brownell et al (2010) suggested the awareness of body to one's own body size begins to emerge in the second year of life but in very limited ways and continues developing over the childhood.

In contrast to our prediction, significant differences were not found between the preterm and full-term groups regarding their performance scores. But they differed in reaction time; preterm children solve this task slower than the control. As Milner and Goodale (1995) noted the reaction time of a particular hand action refers to the transformation speed of the visuospatial information into motor execution. This process is the function of the dorsal stream, and the longer reaction time in preterm children suggests an impairment of dorsal system functioning. This finding is consistent with other studies (Braddick, Atkinson and Wattam-Bell, 2003, Taylor, Jakobson, Maurer and Lewis, 2009) suggesting the increased vulnerability of the dorsal stream in children born prematurely. The different amount of time in transforming the visuospatial information into execution is likely to account for the group differences. As we observed, preterm children needed more time to take out the toy from the box through the aperture hole because they had not adjusted their hand to the visuospatial patterns in advance.

To study children's knowledge of body topography we created two age-appropriate modifications of previously used tasks, we investigated the children's topographic body knowledge using typical human bodies versus scrambled bodies portrayed in various postures. Preterm children tended more frequently to fail to discriminate the canonical body posture from the scrambled body, especially in that case when the arms and legs were interchanged. Our findings suggest that children aged 4 years are able to discriminate the canonical human body confidently regardless of the body posture. This result is not surprising, because even toddlers are capable to discriminate the scrambled body from the typical body (Slaughter et al., 2003). In the other body topography (body part localization) task children were asked to point body parts by name. The findings showed that full-term children are superior. The preterm children's poor performances remind us of the neuropsychological deficit at the level of lexical-semantic body representation, patients (autotopagnosia) with damage to the left parietal area have difficulties to localize their own body parts when the examiner names them, but they can identify parts of inanimate objects (Guariglia et al., 2002). These results suggest dissociation between the topographic representation and semantic representation of their own body. Nevertheless, in our preterm sample we did not find that the semantic representation is dissociated from the visuospatial representation, because the children's performance of body part localization correlated with the performance score in scrambled body task (for whole body r =.405 p < .04). Notably, the impairments in movement-related representations (hand fitting) of one's body did not correlate with the two other representational levels either in the preterm sample or in the whole sample. Such findings suggest that sensori-motor body representation might be a distinct aspect of the body representation.

The last question we addressed refers to the possible relationship between the body-related representations and spatial abilities in preterm children. Our data suggested that the production of spatial language from two different spatial viewpoints, using allocentric vs. egocentric frame of reference, was associated with the body representations, namely the preterm children who showed better performance in the body location tasks obtained better outcomes of spatial language production (within the allocentric reference). Moreover, the performance of hand fitting task also correlated with the spatial language productions. It seems that the body might play an important role in the spatial representation as the popular theory of embodiment suggested. The body is used as a sort of reference frame (head-feet, front-back, left-right) which is mapped onto the embodied objects, for example 'I am behind the melon' (Lakoff and Johnson, 1999). However, the speaker can use a viewer-centered (egocentric or deictic) or object-centered (allocentric or intrinsic) frame of reference, and using the allocentric rather than egocentric spatial reference frame to describe the spatial relations can refer to the objective and viewpoint independent approach of the world. In fact, preterm children's production of egocentric spatial language correlated with the movement-related body representation. We propose children who use an egocentric view to describe the scene are involved bodily. An impaired sensori-motor body representation is not allowed to provide a stable egocentric reference point to determine the locations.

Conclusion

This study is the first to examine the different levels of body knowledge associated with some spatial abilities in children born very prematurely. Relative to full-term sample, preterm children showed reduced performance in all levels of body representation which are associated to the production of spatial language.

There were theoretical and practical reasons for questioning this issue. From a theoretical point of view only limited number of studies investigated the possible relationship between the body representation and spatial cognition, and none of them focused on the specific developmental risks of preterm birth. Nevertheless, the embodiment theory emphasizes the body experience as a ground of many different psychological functions, such as emotions and cognition. As Esther Thelen (2000) claimed the cognitive processes emerge from the bodily experience as someone is interacting with the world and this experience is constrained by the particular motor and perceptual capabilities. On the other hand, the practical reason of this study is to provide indications for early intervention of cognitive abilities based on the body knowledge that is thought to be a potential predictor of learning disabilities. Our findings suggest that the early body experience is very important for the later development, because infants discover the world through their bodies, e.g. how their bodies move in space, how their bodies relate to the objects in the world (Adolph and Berger, 2006); while they are capable to differentiate their bodies form the physical world from the first year of the life. Therefore, from a practical view, the early intervention to improve these children's body knowledge at all levels is worthy of consideration.

Limitations. Our results must be viewed with caution for some reasons. First, we did not control the birth weight relative to gestational weeks, our preterm sample involved children with relatively wide range (600 g to 1680 g) however previous studies showed that the birth weight (as a degree of prematurity) is a good predictor of the future cognitive abilities. Second, it is not clear whether the results of preterm children are specific to body representations or the problem in body representation itself is a consequence of prior deficit. The future work should explore how the body representation relates to prematurity specifically.

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